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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-39 THROUGH J4-1801-41)

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ARO, Inc.

February 1969

LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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Per AF Letter

William O. Cole

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space System Division, manufacturer of the S-IVB stage. The testing reported herein was conducted between April 30 and June 5, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on October 28, 1968.

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This technical report has been reviewed and is approved.

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ABSTRACT

Fourteen firings of the Rocketdyne J-2 rocket engine performed in Test Cell J-4 of the Large Rocket Facility, using modified augmented spark igniter propellant supply lines, are reported herein. These firings were accomplished during test periods J4-1801-39 through J4-1801-41 at pressure altitudes ranging from 88, 000 to 109, 000 ft at engine start. These were the initial firings at simulated altitude conditions, all related to Saturn V/S-IVB conditions, incorporating engine modifications that were performed as a result of malfunctions that occurred during the flight of vehicle AS-502 on April 4, 1968. Engine start transient evaluations, augmented spark igniter propellant line strain data, engine steady-state and transitory vibration data, and calculated engine steady-state performance data are included. Satisfactory engine operation and augmented spark igniter operation were obtained. The accumulated firing duration was 181. 7 sec.

Per AF Letter dtd 24 August
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William O. Cole

CONTENTS

APPENDIXES

I. ILLUSTRATIONS

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that the helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
MSCS	Main-stage control solenoid

STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 engine (S/N's J-2052 and J-2047) using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The 14 firings reported herein ended a test series on engine S/N J-2047 with a total of 115 engine firings having been accomplished for an accumulated firing duration of 1483 sec in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were accomplished at pressure altitudes ranging from 88,000 to 109,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start and with selected engine components conditioned to the expected range of environmental temperatures for the Saturn V/S-IVB stage.

The tests reported herein were conducted on April 30, May 30, and June 5, 1968, to verify safe and reliable start, operation, shutdown, and restart of the 230,000-lb_f-thrust-rated J-2 engine with augmented spark igniter propellant supply line modifications that were made by the engine manufacturer as a result of the anomolies that occurred during flight AS-502 on April 4, 1968 (Ref. 2). Post-flight evaluation of flight AS-502 telemetered data led to the conclusion that the augmented spark igniter fuel supply line on S-II engine No. 2 failed and ultimately caused failure of the engine. Also, results thus far indicate, according to Ref. 3, that a leak in the S-IVB engine augmented spark igniter fuel supply system probably occurred, resulting in a thrust performance shift during first burn and the failure to achieve restart after a two-orbit coast period.

Since the flight, Ref. 3 indicates that testing at Marshall Space Flight Center (MSFC) and the engine manufacturer's facility has substantiated these conclusions. The testing revealed that an oxidizer-rich mixture in the augmented spark igniter, caused by a fuel leak, creates very high temperatures and rapid erosion of the thrust chamber injector. Because of this erosion, the oxidizer dome of S-II engine No. 2 eventually failed, opening the oxidizer high pressure system and causing engine cutoff. One test conducted at an augmented spark igniter mixture ratio (oxidizer-to-fuel) of seven resulted in injector damage simulating performance changes recorded on the AS-502 flight.

The engine manufacturer had already instigated a design improvement to be incorporated on 230,000-lb_f-thrust-rated engines for the

augmented spark igniter fuel supply line at the time of the AS-502 flight (the AS-502 engines were 225,000-lb_f-thrust-configuration engines). It was this modification, called the interim-configuration fuel supply line for the purposes of this report, that was tested for the first time on an engine at simulated altitude conditions during test 39 on April 30. However, a modification of both augmented spark igniter propellant feed lines (oxidizer and fuel) has been accomplished as a result of the AS-502 flight. The newly modified lines were tested for the first time at simulated altitude conditions during tests 40 and 41 on May 30 and June 5, 1968. Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during these tests have been previously supplied to the sponsor, and copies are on file at AEDC. The results of previous tests at AEDC conducted between April 16 and 23, 1968, are presented in Ref. 4.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage with flight-type S-IVB stage low pressure propellant supply ducts was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed between test periods are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 5) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio

of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs. The igniter continues to operate until engine cutoff with approximately 1.5-lb_m/sec propellant flow at main-stage conditions.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1101 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation (Figs. 6 and 7).

2.1.2 Augmented Spark Igniter Propellant Feed Line Modifications

The basic modification performed to the augmented spark igniter fuel supply line was the elimination of the three flexible hose sections that were in the original line. Figure 8 shows the modified line as installed on the engine compared to the original line configuration, shown removed. The original fuel line was made in two sections: the 209732 lower line containing two 0.625-in.-diam single-bellows, single-braid overlap flexible hoses, and the NA5-260035 upper line containing one

0.5-in.-diam single-bellows, single-braid overlap flexible hose. The upper fuel line included an instrumentation block with provisions for measuring augmented spark igniter fuel injection pressure and temperature. The lower line contained a tee for topping off the start tank from the high pressure liquid hydrogen source through a 0.054-in.-diam orifice.

The interim modification, incorporated for test 39, was installed under Rocketdyne Field Directive[1] AEDC-21-68 and replaced the lower fuel line with a solid 0.625-in.-diam line eliminating the two lower line flexible hoses. This modification incorporated a flexible upper line section but of improved strength — a triple-bellows, double-braid overlap NA5-260161 hose. The interim modification retained the instrumentation block in the upper fuel line. This configuration, before the AS-502 flight, was to have been incorporated on 230,000-lb_f-thrust-rated engines (S/N's J-2060 and subsequent engines).

The post-flight AS-502 modification to the augmented spark igniter fuel line, Engineering Change Proposal[2] 643, eliminated the upper line flexible hose, incorporating a solid 0.5-in.-diam stainless steel line. The instrumentation block was eliminated also, and an orifice fitting was included in its place for calibration of the desired fuel supply rate to the augmented spark igniter injector. A 0.263-in.-diam fuel line orifice was utilized for test 40. A 0.302-in.-diam orifice was installed for test 41. The new fuel line, a replacement augmented spark igniter chamber and injector assembly, and a new oxidizer line were installed under Rocketdyne Field Directive AEDC-24-68. Details of the interim and new fuel line configurations are compared in Figs. 8b through g. The new oxidizer line is shown in Fig. 9. The field directive also changed the size of the start tank topping line orifice from 0.054- to 0.070-in. diameter.

Engineering Change Proposal 643 made only a minor change in the 0.375-in.-diam stainless steel augmented spark igniter oxidizer line from the configuration that had been used on engine S/N J-2047 throughout the AEDC test series, Engineering Change Proposal 575, modification 267. The design modification changed the location of the line orifice to the augmented spark igniter oxidizer valve outlet flange, eliminating an in-line-welded sleeve orifice fitting at the line midsection. The

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[1]Rocketdyne Field Directive, Effectivity AEDC

[2]Engineering Change Proposal, Rocketdyne Division, North American Rockwell Corporation.

design modification also fixed the size of this orifice at 0.125-in. diameter. Heretofore, the oxidizer line orifice size had been varied over a range from 0.110- to 0.150-in. diameter in the AEDC test program. For test 39, two oxidizer line orifices had been used, one at the line midsection and one at oxidizer valve outlet flange, which provided a combined pressure drop equivalent to a single 0.110-in.-diam orifice.

2.1.3 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both the fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility vent system for each firing. For firings of 32.5-sec duration, it was programmed off at t_0 + 7.5 sec using a facility shutoff valve.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), liquid oxygen, and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls,

and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 6.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, and main oxidizer valve. Conditioned helium was routed internally through the crossover duct and tubular-walled thrust chamber, and ambient temperature helium was routed externally over the main oxidizer valve second-stage actuator to warm as required after propellants were admitted to the engine.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the

flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome, on the turbopumps, the main fuel valve, augmented spark igniter oxidizer valve, oxidizer turbine bypass valve, and augmented spark igniter fuel supply line. Strain levels on the augmented spark igniter fuel and oxidizer propellant supply lines were measured using single-active arm, temperature-compensating strain gages. The active arm was bonded to the line in the axial direction. An unbonded arm in the hoop direction provided temperature compensation. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, strain-gage units, and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (Microsadic®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted to a greater than 96-percent nitrogen atmosphere. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required,

using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Fourteen firings of the J-2 rocket engine were conducted between April 30 and June 5, 1968, during test periods J4-1801-39 and -41. Test conditions simulated S-IVB first burn or orbital restart conditions. These firings related to integrity verification of the modified augmented spark igniter propellant supply lines during engine operation and to evaluation of engine ignition temperature transients in the augmented spark igniter during start at altitude conditions.

Test objectives were met, and satisfactory engine operation was obtained. Augmented spark igniter operation was satisfactory during all of the firings. Five firings for an accumulated duration of 56.49 sec were accomplished using the interim configuration fuel line and 0.110-in.-diam oxidizer line orificing; nine firings for an accumulated duration of 125.21 sec were accomplished using the post-flight AS-502 modification lines and a replacement augmented spark igniter injector assembly. Using a 0.125-in.-diam orifice in the modified oxidizer line, fuel orifice sizes were chosen to provide a nominal main-stage mixture ratio in the augmented spark igniter of 0.556 for test 40 and 0.361 for test 41. (Design mixture ratio for the Engineering Change Proposal 643 assembly is 0.485 ± 0.03.) Refer to Appendix IV for engine manufacturer flow-calibration test data of the new lines before shipment and for configuration and orificing details.

Test conditions at engine start were selected to provide extreme starting conditions of maximum or minimum propellant inlet pressure limits for high augmented spark igniter temperature or for late ignition of propellants in the igniter, respectively. Augmented spark igniter temperature levels during the ignition transient were found to have a direct relationship with chilldown characteristics of the fuel supply line.

A summary of test requirements and results is presented in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Figure 10 shows engine start conditions for turbopump inlets, the start tank, and the helium tank at engine start for each firing.

The presentation of the test results in the remainder of this section will consist first of a discussion of each firing; secondly, data comparisons between firings to illustrate augmented spark igniter temperature transient characteristics; and thirdly, typical propellant line strain and related vibration data during engine start and main-stage operation. The data presented are primarily those recorded on the digital data acquisition system, except for strain and vibration data which were recorded on the FM system. Other exceptions are as noted.

4.2 TEST RESULTS

4.2.1 Test J4-1801-39

4.2.1.1 Firing J4-1801-39A

4.2.1.1.1 Objectives

The objectives were to evaluate augmented spark igniter and gas generator temperature transients for S-IVB first burn start at minimum start tank energy, minimum oxidizer pump inlet pressure, maximum fuel pump inlet pressure, and warmest expected thrust chamber temperature.

4.2.1.1.2 Results

Firing 39A was 32.571 sec in duration after a 3-sec fuel lead. A propellant utilization valve excursion from null to full closed was made at approximately t_0 + 12 sec (effectively changing mixture ratio from 5.0 to 5.5). All engine start conditions were within specified target limits. The temperature conditioning histories of engine components are shown in Fig. 11. Test cell pressure altitude at engine start was 99,500 ft.

Engine start and shutdown transient parameters are presented in Fig. 12. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 13. Fuel pump start transient performance is shown in Fig. 14. Fuel pump and oxidizer pump inlet pressures were high (41.9 psia) and low (33.9 psia), respectively, to provide low oxidizer-to-fuel mixture ratio in the augmented spark igniter for ignition.

Augmented spark igniter ignition was detected at t_0 + 0.429 sec, 21 msec before expiration of the ignition phase timer.[3] (See Ref. 8 for description of ignition detection safety function.)

Associated with the abnormally late ignition detect time was an apparent discrepancy in augmented spark igniter fuel injection temperature data through the ignition phase of the start transient of this firing. However, from examination of fuel injection pressure and fuel supply line skin temperature data, augmented spark igniter operation appears to have been satisfactory with successful ignition using this pump inlet pressure ratio, oxidizer-to-fuel, of 0.8. The indicated augmented spark igniter chamber temperature peak was 200°F, occurring at oxidizer dome prime. (The augmented spark igniter ignition detect probe temperature was used for igniter chamber temperature determination as shown in Appendix V.)

Engine start transient results were consistent with previous results for firings conducted with low starting energy. Thrust chamber ignition, i.e., oxidizer dome prime (Appendix VI), occurred at t_0 + 1.015 sec with 38 msec of vibration safety counts. The gas generator peak temperature was 1326°F. The main oxidizer valve began second-stage ramping movement at 1.014 sec. Thrust chamber pressure buildup to 550 psia (main-stage operation) required 1.972 sec.

4.2.1.2 Firing J4-1801-39B

4.2.1.2.1 Objectives

The objectives were to evaluate augmented spark and gas generator temperature transients for S-IVB first orbit (80-min) restart utilizing narrow band start tank relief valve start targets, minimum oxidizer pump inlet pressure, and maximum fuel pump inlet pressure.

4.2.1.2.2 Results

Firing 39B was 7.589 sec in duration after an 8-sec fuel lead. Engine restart was initiated 24 min after cutoff of firing 39A when the crossover duct (oxidizer turbine vicinity) had cooled to 169°F, the level predicted for S-IVB first orbit (80-min) restart. The thrust chamber was warmed with ambient temperature helium to 42°F at engine start.

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[3]Augmented spark igniter ignition must be detected before the ignition phase timer expires at t_0 + 0.45 sec) or automatic engine cutoff will occur.

Start tank conditions were targeted to the narrow-band pressure relief valve start limit for -260°F start tank temperature incorporated on J-2 engines for the restart application (see Ref. 7). The propellant utilization valve was maintained in the open position for the duration of this firing. Fuel pump and oxidizer pump inlet pressures were near the maximum for fuel (41.8 psia) and minimum for oxidizer (34.0 psia), respectively, to provide a low mixture ratio for augmented spark igniter ignition.

The temperature conditioning histories of engine components are shown in Fig. 15. Test cell pressure altitude at engine start was 99,500 ft. All engine start conditions were within specified target limits. Engine start and shutdown parameters are presented in Fig. 16. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 17. Fuel pump start transient performance is shown in Fig. 18.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.793 sec after engine start. The augmented spark igniter ignition detect probe output voltage was low throughout the ignition phase, indicating a maximum peak temperature of 100°F at oxidizer dome prime.

Oxidizer dome prime occurred at t_0 + 0.963 sec with 35 msec of vibration safety counts. The gas generator reached a peak temperature of 1370°F. The main oxidizer valve began to ramp from the first-stage position at t_0 + 1.105 sec. A second peak of 1395°F in gas generator temperature occurred at t_0 + 1.15 sec. Very conservative fuel pump stall margin was maintained throughout the engine start transient. Thrust chamber pressure buildup to 550 psia required 2.050 sec from t_0.

4.2.1.3 Firing J4-1801-39C

4.2.1.3.1 Objectives

The objectives were to evaluate augmented spark igniter and gas generator temperature transients for S-IVB restart after 6-hr orbital coast utilizing minimum start tank energy and minimum oxidizer and fuel pump inlet pressures.

4.2.1.3.2 Results

Firing 39C was accomplished approximately 1 hr after firing 39B. This firing was 7.589 sec in duration after an 8-sec fuel lead with conditions at engine start simulating those predicted for S-IVB orbital restart after a 6-hr coast period. Engine start conditions included low

starting energy, reduced fuel and oxidizer pump inlet pressures (27.2 and 33.3 psia, respectively), and the thrust chamber warmed with ambient temperature helium to 45°F. The propellant utilization valve was maintained in the open position throughout the duration of this firing.

All engine start conditions were within specified target limits. The temperature conditioning histories of engine components are shown in Fig. 19. Test cell pressure altitude at engine start was 105,000 ft.

Engine start and shutdown transient parameters are presented in Fig. 20. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 21. Fuel pump start transient performance is shown in Fig. 22.

Augmented spark igniter operation was satisfactory. Ignition was detected in the augmented spark igniter 0.356 sec after engine start. Indicated augmented spark igniter probe temperature reached a first peak of approximately 1000°F at t_0 + 0.25 sec just before spinup of the fuel turbopump and a second peak of approximately 1000°F at oxidizer dome prime.

Oxidizer dome prime occurred at t_0 + 1.073 sec with 12 msec of vibration safety counts. The main oxidizer valve began second-stage ramping movement at t_0 + 1.082 sec. The start transient of this firing was consistent with previous low energy starts. The gas generator peak temperature (at oxidizer dome prime) was only 720°F, the lowest recorded to date on either engine S/N J-2052 or J-2047 at AEDC. Thrust chamber pressure buildup to 550 psia required 2.607 sec from t_0.

4.2.1.4 Firing J4-1801-39D

4.2.1.4.1 Objectives

The objectives were to evaluate augmented spark igniter operation at the coldest expected thrust chamber temperature for an S-IVB start with a propellant inlet pressure ratio (oxidizer-to-fuel) of approximately 0.8.

4.2.1.4.2 Results

Firing 39D was accomplished 49 min after cutoff of firing 39C for 7.588-sec duration after a 3-sec fuel lead. Engine start target conditions were satisfactorily met. Temperature conditioning histories of engine components are shown in Fig. 23. Test cell pressure altitude at engine start was 102,500 ft.

The thrust chamber was prechilled to -294°F average temperature at engine start. Fuel pump inlet pressure was maximum (42.2 psia) and oxidizer pump inlet pressure minimum (33.8 psia). Engine start and shutdown transient parameters are presented in Fig. 24. Test cell pressure and thrust chamber pressure for the firing duration are shown in Fig. 25. Fuel pump start transient performance is shown in Fig. 26.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.206 sec after engine start. Indicated augmented spark igniter probe temperature was a maximum of 800°F at t_0 + 0.20 sec.

Low starting energy coupled with extremely cold thrust chamber temperature at engine start produced an unusual start transient for this firing, characterized by a thrust chamber flow reduction after oxidizer dome prime and a second dome prime. There was low gas generator power development during the bootstrap period (before the first prime), resulting in low gas generator peak temperature, 1370°F; both results are consistent with the low starting energy.

There was thrust chamber combustion instability from main propellant ignition, which registered a shock on the oxidizer dome accelerometers exceeding 150 g rms for 10 msec (see Fig. 26), to oxidizer dome prime. This type of instability has occurred during previous engine starts with extremely cold thrust chamber temperatures and very high thrust chamber fuel lead flow rates (approximately 1500 gpm before start tank discharge for this firing). This mode of instability from main propellant ignition to oxidizer dome prime is shown in Fig. 26 to be characterized by thrust chamber pressure fluctuations of approximately 15-psi peak-to-peak at a frequency of approximately 80 Hz. The temperature sensing probe for gaseous nitrogen purge gas on the oxidizer dome indicated a rise in temperature of about 30°F during this same time period. These data indicate the possibility of combustion taking place within the oxidizer dome.

Sporadic vibration safety counts began as thrust chamber pressure fluctuations increased in amplitude beginning at approximately t_0 + 0.98 sec. When the main oxidizer valve began second-stage ramping movement at t_0 + 0.990 sec, thrust chamber pressure reached a peak of 260 psia (FM data). Fuel pump stall margin reduced to approximately 250 gpm as fuel flow decreased by 1500 gpm and fuel pump discharge pressure peaked to approximately 400 psia. The oxidizer flow rate momentarily decreased by 260 gpm (FM data) at the same time oxidizer pump discharge pressure reached a peak of approximately 250 psia. These thrust chamber flow reductions resulted in the thrust chamber pressure decrease and the cessation of vibration safety counts. Resultant propellant pressure

increases to the gas generator caused both turbopumps to accelerate with the power increase and decreasing back pressure, initiating the second prime and another period of vibration safety counts for 21 msec at t_0 + 1.25 sec. During the second dome prime, the fuel pump stall margin reduced to approximately 400 gpm. Thrust chamber pressure then proceeded to build up to main-stage operating level, smoothly attaining 550 psia at t_0 + 2.067 sec. The propellant utilization valve was maintained in the null position (approximately 5.0 engine mixture ratio at main stage) throughout the firing duration.

4.2.1.5 Firing J4-1801-39E

4.2.1.5.1 Objectives

The objectives were to evaluate augmented spark igniter operation for an S-IVB partial transition firing with ambient temperature thrust chamber and an oxidizer-to-fuel pump inlet pressure ratio of approximately 1.1.

4.2.1.5.2 Results

Firing 39E was 1.150 sec in (programmed) duration after a 3-sec fuel lead. All engine start target conditions were satisfactorily met. The temperature conditioning histories of engine components are shown in Fig. 27. Test cell pressure altitude at engine start was 109,000 ft. The propellant utilization valve was in the null position.

Engine start and shutdown transient parameters are presented in Fig. 28. Test cell pressure and thrust chamber pressure during the firing are presented in Fig. 29. Fuel pump start transient performance is shown in Fig. 30. Fuel and oxidizer pump inlet pressures were both at maximum safe operating limits, 40.6 and 46.0 psia, respectively. Thrust chamber temperature was 60°F at engine start.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.242 sec after engine start. Indicated probe temperature reached a maximum of 1200°F at t_0 - 0.125 sec. The augmented spark igniter fuel supply line chilldown data in Fig. 28 (pressure and temperature data) reveal that fuel flow decreased as the fuel lead period progressed. Augmented spark igniter fuel injection temperature reached a plateau of only -165°F at approximately t_0 - 3 sec, which lasted until fuel pump spinup. With reduced fuel flow to the augmented spark igniter, mixture ratio increased, producing the 1200°F temperature peak.

Oxidizer dome prime occurred at t_0 + 0.974 sec with 10 msec of vibration safety counts. Gas generator temperature rose to a first peak

of 1650°F and a second peak of 1980°F immediately after engine cutoff. The main oxidizer valve began second-stage ramping movement at t_0 + 1.109 sec. All of these results were consistent with the high starting energy conditions for this firing. Low frequency, 80-Hz, thrust chamber pressure oscillations existed from main propellant ignition to oxidizer dome prime. Conservative fuel pump stall margin was maintained throughout the duration of the partial transition firing.

4.2.2 Test J4-1801-40

4.2.2.1 Firing J4-1801-40A

4.2.2.1.1 Objectives

The objectives were to evaluate augmented spark igniter operation at maximum augmented spark igniter mixture ratio and warm thrust chamber conditions for S-IVB first burn start.

4.2.2.1.2 Results

Firing 40A was 2.182 sec in duration following a 3-sec fuel lead. The thrust chamber was conditioned to an average temperature of -102°F at engine start. Temperature conditioning histories of engine components are shown in Fig. 31. Test cell pressure altitude at engine start was 88,000 ft. All engine start conditions were satisfactorily obtained with the exception of propellant utilization valve position (see Fig. 32).

Engine start and shutdown transient parameters are presented in Fig. 33. Test cell pressure and combustion chamber pressure during the firing are shown in Fig. 34. Fuel pump start transient performance is presented in Fig. 35. Fuel pump and oxidizer pump inlet pressures were minimum (26.7 psia) and maximum (46.1 psia), respectively. The main oxidizer valve second-stage initial movement occurred at t_0 + 1.153 sec.

Firing 40A was scheduled as a 32.5-sec firing with a propellant utilization valve excursion from null to closed at t_0 + 10 sec to effectively change the mixture ratio from 5.0 to 5.5. However, the propellant utilization valve was inadvertently closed at t_0 - 0.652 sec (Fig. 32).

Under this condition, gas generator chamber pressure rose rapidly at oxidizer dome prime with gas generator outlet temperature rising to, and remaining at, nearly 2000°F from dome prime until engine cutoff, which was automatically initiated by fuel pump overspeed safety cutoff

(Fig. 33a) at t_0 + 2.182 sec. The fuel pump spun to 29,450-rpm peak at cutoff, and the oxidizer pump spun to 9300 rpm. The main oxidizer valve encountered sufficient hydraulic torque as a result of the increased oxidizer differential pressure that the valve never opened further than 30 percent of its full open position during the entire start transient.

Augmented spark igniter ignition was detected 0.212 sec after engine start and attained an initial peak temperature of 400°F at t_0 + 0.5 sec. A second peak of 400°F occurred at t_0 + 1.2 sec. Augmented spark igniter operation was satisfactory during this firing.

4.2.2.2 Firing J4-1801-40AA

4.2.2.2.1 Objectives

The objectives were to evaluate augmented spark igniter temperature transients at maximum augmented spark igniter mixture ratio and flow conditions with warm thrust chamber conditions for S-IVB first burn start.

4.2.2.2.2 Results

Firing 40AA was of 32.577-sec duration following a 3-sec fuel lead. An average thrust chamber temperature of -102°F was obtained during helium prechill. All engine start conditions were within specified target limits. Temperature conditioning histories of various engine components are presented in Fig. 36. Test cell pressure altitude at engine start was 92,000 ft.

Engine start and shutdown transients are presented in Fig. 37. Test cell pressure and combustion chamber pressure for this firing are presented in Fig. 38. Fuel pump start transient performance is shown in Fig. 39. Fuel and oxidizer pump inlet pressures were both maximum (41.6 and 46.0 psia, respectively).

Firing 40AA included a propellant utilization valve excursion from null to fully closed at t_0 + 12.5 sec, effectively changing the oxidizer-to-fuel mixture ratio from 5.0 to 5.5. Augmented spark igniter ignition was detected 0.202 sec after engine start and reached an initial temperature peak of 800°F with a second peak of 700°F at oxidizer dome prime at t_0 + 0.962 sec. Augmented spark igniter operation was satisfactory during this firing.

Vibration safety counts occurred for 51 msec beginning at t_0 + 0.955 sec. A gas generator initial peak temperature of 1567°F

occurred at t_0 + 1.025 sec. The main oxidizer valve second-stage movement occurred at t_0 + 1.129 sec and required 2.109 sec to attain its fully open position. Thrust chamber pressure buildup to 550 psia required 1.829 sec.

4.2.2.3 Firing J4-1801-40B

4.2.2.3.1 Objectives

The objectives were to evaluate augmented spark igniter operation at maximum augmented spark igniter mixture ratio and warm thrust chamber temperature for S-IVB first orbit (80-min) restart.

4.2.2.3.2 Results

Firing 40B of 7.590-sec duration was conducted 35 min after firing 40AA following an 8-sec fuel lead when the crossover duct had cooled to 172°F for this S-IVB first orbit (80-min) restart simulation. The thrust chamber was conditioned to an average temperature of 37°F at engine start. All engine start conditions were within specified target limits. Temperature conditioning time histories for various engine components are presented in Fig. 40. Test cell pressure altitude at engine start was 103,000 ft.

Engine start and shutdown transient parameters are shown in Fig. 41. Test cell pressure and combustion chamber pressure are presented in Fig. 42. Fuel pump start transient performance is presented in Fig. 43. Fuel pump and oxidizer pump inlet pressures were minimum (36.5 psia) and maximum (45.6 psia), respectively. The propellant utilization valve was open (4.4 mixture ratio) during this firing. Oxidizer dome prime occurred at t_0 + 0.957 sec with engine vibration safety counts occurring for 3 msec starting at t_0 + 1.028 and again for 3 msec at t_0 + 1.234 sec.

Gas generator initial peak temperature was 1716°F at t_0 + 1.025 sec with a second peak of 1824°F 225 msec later. Main oxidizer valve second-stage initial movement occurred at t_0 + 1.134 sec and required 1.958 sec to ramp open. Thrust chamber pressure buildup to 550 psia required 2000 sec from t_0.

Augmented spark igniter operation was satisfactory during this firing. Ignition was detected 0.215 sec after engine start, and the igniter chamber experienced a maximum temperature of 600°F.

4.2.2.4 Firing J4-1801-40C

4.2.2.4.1 Objectives

The objectives were to evaluate augmented spark igniter operation at maximum augmented spark igniter mixture ratio and cold thrust chamber conditions for S-IVB restart.

4.2.2.4.2 Results

Firing 40C, an S-IVB restart simulation, was 32.577 sec in duration following an 8-sec fuel lead. The thrust chamber was conditioned to an average temperature of -236°F at engine start. Temperature conditioning histories for various engine components are presented in Fig. 44. Test cell pressure altitude at engine start was 99,000 ft.

Engine start and shutdown transients are presented in Fig. 45. Test cell and combustion chamber pressures are shown in Fig. 46, and fuel pump start transient performance is presented in Fig. 47. All engine start conditions were within specified target limits. Fuel pump inlet pressure at engine start was minimum (27.5 psia), and oxidizer pump inlet was maximum (45.3 psia).

Oxidizer dome prime occurred at t_0 + 1.032 sec with 25 msec of vibration safety counts beginning at t_0 + 1.027 sec and again for 16 msec beginning at t_0 + 1.234. The main oxidizer valve second-stage movement required 1.890 sec, beginning at t_0 + 1.027 sec. A propellant utilization valve excursion from the open position to fully closed was accomplished at t_0 + 10.5 sec, effectively changing the oxidizer-to-fuel mixture ratio from 4.4 to 5.5.

Gas generator initial peak temperature was 1378°F. Thrust chamber ignition occurred 1.032 sec after t_0, and thrust chamber pressure buildup to 550 psia required 2.164 sec from t_0.

Augmented spark igniter ignition was detected 0.189 sec after engine start and reached an initial temperature peak of 300°F approximately 2 sec later (Fig. 45k). During thrust chamber ignition transient at approximately t_0 + 0.7 sec (Fig. 45l), voltage output from the augmented spark igniter probe became erratic, apparently because of the severe environment caused by combustion instability, and short-circuited at t_0 + 1.725 sec. At t_0 + 2.30 sec, the augmented spark igniter probe regained its operational ability and performed satisfactorily throughout the remainder of the firing.

4.2.2.5 Firing J4-1801-40D

4.2.2.5.1 Objectives

The objectives were to evaluate augmented spark igniter operation at maximum augmented spark igniter mixture ratio and flow conditions with warm thrust chamber conditions for S-IVB first orbit (80-min) restart.

4.2.2.5.2 Results

Firing 40D was conducted 29 min after firing 40C and was 7.590 sec in duration following an 8-sec fuel lead. Engine restart was initiated when the crossover duct had cooled to 177°F for this S-IVB first orbit (80-min) restart simulation. The thrust chamber was warmed to an average temperature of 48°F at engine start. All engine start target conditions were satisfactorily obtained. Temperature conditioning histories of various engine components are presented in Fig. 48. Test cell pressure altitude for this firing was 104,000 ft at engine start.

Engine start and shutdown transients are shown in Fig. 49. Figure 50 presents test cell pressure and combustion chamber pressure, and fuel pump start transient performance is presented in Fig. 51. Fuel pump and oxidizer pump inlet pressures at engine start were both maximum (41.2 and 45.6 psia, respectively).

Oxidizer dome prime occurred at $t_0 + 0.953$ sec with 17 msec of vibration safety counts beginning at $t_0 + 0.960$ sec. Gas generator initial peak temperature was 1807°F with a second peak of 1767°F. The main oxidizer valve second-stage movement began at $t_0 + 1.109$ sec and required 1.944 sec to reach its fully opened position. Thrust chamber pressure reached 550 psia at $t_0 + 1.945$ sec. The propellant utilization valve remained open throughout this firing.

During firing 40D, augmented spark igniter ignition was detected 0.272 sec after engine start (Fig. 49k) and reached a peak of 700°F. At approximately 3.1 sec after engine start, the augmented spark igniter probe output voltage became erratic, and the probe appeared to fail 0.5 sec later. After $t_0 + 1.7$ sec, the probe appeared to have a normal output throughout the remainder of the firing; however, the probe finally became completely inoperable several minutes after the firing.

4.2.3 Test J4-1801-41

4.2.3.1 Firing J4-1801-41A

4.2.3.1.1 Objectives

The objectives were to evaluate augmented spark igniter operation at minimum augmented spark igniter mixture ratio and warm thrust chamber conditions for S-IVB first burn start.

4.2.3.1.2 Results

Firing 41A was 32.575 sec in duration following a 3-sec fuel lead. The thrust chamber was prechilled to -109°F at engine start. All engine start target conditions were satisfactorily met. Temperature conditioning histories are shown in Fig. 52. Test cell pressure altitude was 102,000 ft at engine start.

Engine start and shutdown transient parameters are presented in Fig. 53. Test cell and combustion chamber pressures during the firing are shown in Fig. 54. Fuel pump start transient performance is shown in Fig. 55. Fuel pump and oxidizer pump inlet pressures were maximum (41.3 psia) and minimum (33.5 psia), respectively.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.558 sec after engine start. The indicated probe temperature reached a maximum of 100°F.

Oxidizer dome prime occurred at t_0 + 1.007 sec with 134 msec of vibration safety counts. The peak gas generator temperature was 1130°F with a second peak of 1230°F. The main oxidizer valve began second-stage ramping movement at t_0 + 1.014 sec. Thrust chamber pressure buildup to 550 psia required 1.995 sec from t_0. A propellant utilization valve excursion from null to closed was accomplished at t_0 + 13.5 sec, effectively changing engine mixture ratio from 5.0 to 5.5.

4.2.3.2 Firing J4-1801-41B

4.2.3.2.1 Objectives

The objectives were to evaluate augmented spark igniter operation at minimum augmented spark igniter mixture ratio and cold thrust chamber conditions for S-IVB first orbit (80-min) restart.

4.2.3.2.2 Results

Firing 41B was conducted 26 min after 41A and was 7.590 sec in duration following an 8-sec fuel lead. The thrust chamber was prechilled to an average temperature of -217°F at engine start. All engine start conditions were within specified target limits. Temperature conditioning histories of engine components are presented in Fig. 56. Test cell pressure altitude was 102,500 ft at engine start.

Engine start and shutdown transients are shown in Fig. 57. Figure 58 presents test cell pressure and combustion chamber pressure during the firing. Fuel pump start transient performance is shown in Fig. 59. Fuel pump and oxidizer pump inlet pressures were maximum (41.3 psia) and minimum (33.7 psia), respectively.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.456 sec after engine start. Indicated probe temperature reached a peak of 1500°F at t_0 - 0.5 sec.

Oxidizer dome prime occurred at t_0 + 0.961 sec with 67 msec of vibration safety counts. The gas generator initial peak temperature was 1560°F. A second peak of 1280°F occurred. The main oxidizer valve began second-stage ramping movement at t_0 + 0.999 sec. Thrust chamber pressure buildup to 550 psia required 2.116 sec from t_0. The propellant utilization valve was maintained in the open position throughout the firing.

4.2.3.3 Firing J4-1801-41C

4.2.3.3.1 Objectives

The objectives were to evaluate augmented spark igniter operation at minimum augmented spark igniter mixture ratio and cold thrust chamber conditions for an S-IVB partial transition firing.

4.2.3.3.2 Results

Firing 41C was conducted for 1.264-sec duration (partial transition) after a 3-sec fuel lead. The thrust chamber was prechilled to an average temperature of -292°F at engine start. All engine start target conditions were satisfactorily met. Temperature conditioning histories of engine components are presented in Fig. 60. Test cell pressure altitude at engine start was 106,500 ft.

Engine start and shutdown transient parameters are presented in Fig. 61. Test cell and combustion chamber pressures during the firing

are presented in Fig. 62. Fuel pump and oxidizer pump inlet pressures were maximum (41.3 psia) and minimum (33.7 psia), respectively. Fuel pump start transient performance is shown in Fig. 63.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.196 sec after engine start. The indicated probe temperature reached a peak of 400°F at t_0 + 0.3 sec.

Oxidizer dome prime occurred at t_0 + 1.048 sec with 51 msec of vibration safety counts. Low frequency, 80-Hz, thrust chamber pressure oscillations existed from main propellant ignition to oxidizer dome prime. The peak gas generator temperature was 1345°F. A second peak of 1200°F occurred after engine cutoff. The main oxidizer valve began second-stage ramping movement at t_0 + 1.006 sec. The propellant utilization valve was held in the null position for this firing.

4.2.3.4 Firing J4-1801-41D

4.2.3.4.1 Objectives

The objectives were to evaluate augmented spark igniter operation at nominal augmented spark igniter mixture ratio and cold thrust chamber conditions for an S-IVB partial transition firing.

4.2.3.4.2 Results

Firing 41D was a partial transition firing 1.258 sec in duration after an 8-sec fuel lead. The thrust chamber was prechilled to an average temperature of -220°F at engine start. All engine start target conditions were satisfactorily met. Temperature conditioning histories of engine components are presented in Fig. 64. Test cell pressure altitude at engine start was 105,000 ft.

Engine start and shutdown transient parameters are presented in Fig. 65. Test cell and combustion chamber pressures during the firing are shown in Fig. 66. Fuel pump start transient performance is shown in Fig. 67. Fuel pump and oxidizer pump inlet pressures were both minimum (26.8 and 33.4 psia), respectively.

Augmented spark igniter operation was satisfactory. Ignition was detected 0.198 sec after engine start. The indicated probe temperature reached a peak of 900°F at t_0 + 0.5 sec.

Oxidizer dome prime occurred at t_0 + 1.090 sec with 58 msec of vibration safety counts. Low frequency, 80-Hz, thrust chamber pressure

oscillations existed from main propellant ignition to oxidizer dome prime. The peak gas generator temperature was 950°F. A second peak of 800°F occurred after engine cutoff. The main oxidizer valve began second-stage ramping movement at t_0 + 1.036 sec. The propellant utilization valve was in the open position for this firing.

4.3 AUGMENTED SPARK IGNITER TEMPERATURE TRANSIENT COMPARISONS

Four data comparisons from the subject firing series illustrate the effects of extreme pump inlet pressure differences and extremely cold thrust chamber temperature on the augmented spark igniter temperature transient. Cooler augmented spark igniter probe temperatures and longer ignition detection delay times generally resulted from using maximum fuel pump inlet pressure with minimum oxidizer pump inlet pressure. Normal ignition detection delay times, from 0.189 to 0.356 sec after engine start, resulted from using an oxidizer pump inlet pressure greater than fuel pump inlet pressure. Higher temperatures generally occurred for the 8-sec fuel lead starts than for the 3-sec fuel lead starts. The extremely cold thrust chamber starts produced higher augmented spark igniter temperatures with firing 41B, yielding the highest of this test series, 1500°F.

Augmented spark igniter fuel supply line chilldown rate was found to be the primary determiner for augmented spark igniter chamber temperature. This parameter reflects the influences of differential pressure variations between the fuel manifold and the augmented spark igniter injector as the fuel supply to the injector changes quality from the gaseous phase eventually to the liquid phase. Data presented in Ref. 7 from engine S/N J-2052, which was instrumented for oxidizer injection pressure and temperature measurements as shown in Appendix IV, Fig. IV-1, show that oxidizer flow stabilizes quickly after engine start with quality change to the liquid phase requiring only about 1 sec after the augmented spark igniter oxidizer valve opens. Certainly, higher oxidizer pump inlet pressures produce corresponding higher oxidizer flow rates, but only moderate augmented spark igniter temperatures (300 to 600°F) were recorded for firings with maximum oxidizer pump inlet pressure and minimum fuel pump inlet pressure in the test series. High oxidizer flow rate and very high thrust chamber fuel flow rate caused reductions in augmented spark igniter fuel flow as the fuel lead periods progressed, resulting in the highest temperatures observed, 1200 and 1500°F, respectively.

4.3.1 Fuel Pump Inlet Pressure Effect

A comparison of data from firings 39B and 39C illustrates the effect of fuel pump inlet pressure extreme differences with minimum oxidizer pump inlet pressure for 8-sec fuel lead starts. Test data are compared below.

	Firing 39B	Firing 39C
Oxidizer pump inlet pressure, psia	34.0	33.8
Fuel pump inlet pressure, psia	41.8	27.2
Augmented spark igniter maximum temperature, °F	100	1000
Thrust chamber temperature at engine start, °F	42	45
Fuel lead time, sec	8	8
Ignition detect time from engine start, sec	0.793	0.356
Ignition detect probe shim thickness, in.	0.084 (approximately same penetration depth as for test 40 using 0.044 shim thickness)[4]	

The significant difference between these two engine starts was 14.6-psia difference in fuel pump inlet pressure. For this analysis, main fuel injection temperature is used to illustrate thrust chamber chilldown rate and fuel lead flow rate, and augmented spark igniter injection temperature is used to illustrate fuel flow rate, differential pressure, and quality change. As shown in Fig. 68, the higher fuel pump inlet pressure for firing 39B resulted in faster chilldown and greater fuel flow to both the thrust chamber and the augmented spark igniter, very cool augmented spark igniter temperature, and delayed ignition detection. As the fuel lead period progressed during firing 39C, the injection temperature data show that the augmented spark igniter fuel supply rate was lower than during firing 39B, accounting for increased mixture ratio and the high temperature during firing 39C.

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[4]The augmented spark igniter injector and chamber assembly used for test 39 was replaced using a new assembly under Rocketdyne Field Directive AEDC-24-68 for tests 40 and 41. Manufacturing tolerances allowed 0.040-in. difference in probe immersion depth, which was compensated for using the appropriate shim thickness.

4.3.2 Oxidizer Pump Inlet Pressure Effect

A comparison of the same parameters from firings 39B and 39E illustrates the effect of maximum oxidizer pump inlet pressure for 8-sec fuel lead starts. Test data are compared below.

	Firing 39B	Firing 39E
Oxidizer pump inlet pressure, psia	34.0	46.0
Fuel pump inlet pressure, psia	41.8	40.6
Augmented spark igniter maximum temperature, °F	100	1200
Thrust chamber temperature at engine start, °F	42	65
Fuel lead time, sec	8	8
Ignition detect time from engine start, sec	0.793	0.242
Ignition detect probe shim thickness, in.	0.084	

The high augmented spark igniter temperature during firing 39E resulted from maximum oxidizer pump inlet pressure, although maximum fuel pump inlet pressure was used. As shown in Fig. 69, the thrust chamber chilldown rate from a 23°F higher bulk temperature at engine start was slightly slower during firing 39E, but there was a significant difference in augmented spark igniter fuel supply line chilldown rates. Augmented spark igniter temperature rose slightly beginning at the injection temperature slope change noted at t_0 - 2 sec during firing 39B but increased to 1200°F when the injection temperature reached a -165°F plateau level at t_0 - 4 sec during firing 39E. Apparently, high augmented spark igniter chamber pressure resulting from the high oxidizer supply pressure for firing 39E effected a sufficient downstream pressure for the augmented spark igniter fuel line to decrease the fuel flow rate. The mixture ratio and temperature condition existed until the start tank discharged, increasing the fuel supply pressure.

4.3.3 Cold Thrust Chamber Effect

A comparison of the data from firings 41A, 41B, and 41C illustrates the effect of extremely cold thrust chamber conditions on the augmented spark igniter temperature transient. Firings 41A and 41C were 3-sec fuel lead S-IVB first burn simulation firings; firing 41B

was an 8-sec fuel lead first orbit (80-min) cold thrust chamber S-IVB restart simulation firing. Test data are compared below.

	Firing 41A	Firing 41B	Firing 41C
Oxidizer pump inlet pressure, psia	33.5	33.7	33.7
Fuel pump inlet pressure, psia	41.3	41.3	41.3
Augmented spark igniter maximum temperature, °F	100	1500	400
Thrust chamber temperature at engine start, °F	-109	-217	-292
Fuel lead time, sec	3	8	3
Ignition detect time from engine start, sec	0.558	0.456	0.196
Ignition detect probe shim thickness, in.	0.024 (approximately 0.020 in. greater penetration depth than for tests 39 and 40)		

Thrust chamber chilldown during the 3-sec fuel lead period of firing 41A produced liquid-phase hydrogen fuel injection temperature at t_0 + 0.5 sec, a result which is consistent with warm thrust chamber prechill S-IVB first burn simulation firings. As shown in Fig. 70, the augmented spark igniter fuel supply line exhibited rapid chilldown. (Data from the single skin thermocouple are substituted for injection temperature since it was the only temperature measurement available on the new fuel line.) A low temperature level and delayed ignition detection resulted from the use of maximum fuel pump inlet pressure with minimum oxidizer pump inlet pressure. The -217°F thrust chamber prechill and 8-sec fuel lead, however, allowed liquid-phase fuel injection temperature to be reached at t_0 - 6 sec with the high fuel pump inlet pressure during firing 41B. The augmented spark igniter fuel line chilldown rate was very slight, although the initial temperature was lower, indicating a low fuel flow rate to the augmented spark igniter for firing 41B. A very low differential pressure apparently existed because of reduced thrust chamber tube resistance and high thrust chamber (therefore augmented spark igniter chamber) pressure. Thus, a high mixture was possible in the augmented spark igniter chamber producing the 1500°F maximum temperature for firing 41B.

Firing 41C provides a direct comparison with firing 41A (Figs. 70c and d), illustrating the cold thrust chamber effect for two 3-sec fuel

lead starts. Furthermore, comparison of firing 41C with 41B shows that, with the cold thrust chamber temperatures, higher igniter chamber temperature results for an extended fuel lead period. The augmented spark igniter temperature rise rate during firing 41C until t_0 (when the start tank discharged) was very rapid because of the cold thrust chamber prechill temperature, -292°F. Low thrust chamber tube resistance was reflected by fuel injection temperature reaching the liquid-phase level in 1 sec after engine start. At these extremely cold conditions, the augmented spark igniter temperature rose to 400°F in 3 sec, before decreasing as the start tank accelerated the fuel pump (increasing the fuel supply to the augmented spark igniter).

4.4 ENGINE VIBRATION AND AUGMENTED SPARK IGNITER PROPELLANT LINE STRAIN

Six new accelerometers and seven temperature-compensating strain gages were installed by the engine manufacturer on engine S/N J-2047 for tests 40 and 41 (see Appendix III, Fig. III-1 for locations). These new measurements were added to the engine with the modified augmented spark igniter propellant lines to obtain data about the vibration environment and the strain levels under which the new-configuration propellant lines must operate.

The oxidizer supply line modification from the Engineering Change Proposal 575 configuration to the Engineering Change Proposal 643 configuration was minor compared to the fuel line changes. The U-shaped configuration and mounting bracket arrangement (refer to Fig. 5) were incorporated in Engineering Change Proposal 575; the new modification only relocated the orifice, eliminating in-place sleeve welds. Changes to the fuel supply line constituted significant redesign as follows. The incorporation of bellows sections in the original line configuration utilized the bellows for the following basic functions:

1. To correct for offset in a relatively tortuous routing from the main fuel manifold to the augmented spark igniter without the necessity of tight production tolerance on installation from engine to engine.
2. To absorb motions of the line caused by thermal contraction at cryogenic temperature (offset, bending, and axial) and the random motions from structural deflections and external vibrations. The strain gages were added to the new fuel supply line to verify that excessive thermal stresses would not occur without the use of the bellows sections.

Stresses, therefore, sustained primarily by the flexible bellows sections in the original fuel line configuration were a combination of the

pressure, thermal, and random stresses. However, another type of random stress related strictly to the flexible bellows may result from mechanically induced vibration caused by high velocity fluid flow through the bellows. Commercial flexible hose manufacturers indicate in the catalogs that fatigue failure of flexible bellows sections can result from fluid velocities normally in excess of 200 fps. This type of flow-induced vibration is believed to have caused fatigue failure of the NA5-260035 single-ply bellows sections on the augmented spark igniter fuel lines of the two AS-502 engines that malfunctioned (Ref. 3). Liquid hydrogen flow rate through the augmented spark igniter fuel line at main-stage operating conditions varies over an approximate range from 0.8 to 1.1 lb_m/sec (for 225,000-lb_f-thrust-configuration engines and varied engine to engine). The higher flow rates (exceeding 1.0 lb_m/sec) occur at maximum thrust conditions (5.5 mixture ratio, closed propellant utilization valve). Uprating the J-2 engine from 225,000- to 230,000-lb_f thrust produced sufficient fuel pump discharge pressure to exceed 1.1-lb_m/sec flow rate and a corresponding fluid velocity in the upper fuel supply line exceeding 200 fps for most production engines. Because of this higher fuel line flow rate, the interim fuel line configuration (NA5-260161 upperline triple-bellows, double-braid overlap) was to have been incorporated on uprated 230,000-lb_f-thrust engines (S/N's J-2060 and subsequent engines[5]) as a strengthening measure. The Engineering Change Proposal 643 modification, as a solution to the flow-induced vibration problem, eliminated the bellows sections altogether.

Strain data acquired during tests 40 and 41 on the new oxidizer and fuel lines are presented in Table VIII, along with vibration amplitudes recorded on the engine accelerometers at corresponding time intervals. The data time intervals selected include:

1. Strain levels at engine start,
2. Strain levels during the ignition phase at t_0 after fuel lead,
3. Strain and vibration levels at oxidizer dome prime during vibration safety count periods,
4. Maximum strain and vibration levels (at approximately t_0 + 2 sec) as the engine accelerates to main-stage operation during start,

---

[5]Reference 3 indicates that the single-ply, single-braid overlap upper fuel line was superseded by the triple-ply, double-braid overlap configuration on engine S/N J-2060 and subsequent engines, because a failure had occurred on an engine at the 230,000-lb_f-thrust level with the single-ply design.

5. Steady-state strain and vibration levels at null, open, and closed propellant utilization valve position, and

6. Strain levels after engine cutoff, following thrust chamber pressure decay to the zero thrust level.

The data show that structural integrity of the new augmented spark igniter propellant lines was completely satisfactory. Steady-state strain levels and oscillatory strain amplitudes indicate that the line routing and attachment points preclude excessive thermal stresses or excessive resonance response of any vibration modes in the lines.

4.4.1 Oscillatory Strain at Oxidizer Dome Prime

The strain gages and all accelerometers clearly registered high amplitude oscillations during vibration safety count periods. Peak amplitudes of approximately 315 to 375 g were recorded on the oxidizer dome accelerometers during oxidizer dome prime. Maximum oscillatory strain levels coincident with these high g levels were recorded at the upper fuel line strain-gage radial location of ±930 μ/in. and ±720 μin./in. during firings 40A and 40AA, respectively. Corresponding maximum oscillatory strain levels on the oxidizer line were recorded at the upstream tangential gage location of ±290 μin./in. and ±365 μin./in., respectively, for these two firings. The highest oxidizer line oscillatory strain recording was at the downstream tangential location, ±410 μin./in., during firing 41B.

4.4.2 Oscillatory Strain during Thrust Buildup to Main Stage

As the engine accelerated to main-stage operation during the start transient of each firing, the fuel line strain gages recorded increasing strain levels as steady-state line pressures and temperatures were achieved. Oscillatory strain levels maximized during each start as pump discharge pressure reached peak overshoot levels before achieving steady-state operation. The peak oscillation levels and time of occurrence for each firing are documented in Table VIII. The lower fuel line axial strain gage registered the highest oscillatory strain concentration during each start transient, reaching maximums of ±400 to ±500 μin./in. during most of the subject firings. This strain gage recorded ±750-μin./in. oscillations during firing 40A. Typical peak oscillations in oxidizer line strain, however, were comparatively low, varying from ±55 to ±104 μin./in. Coincident with the peak strain oscillation amplitudes during acceleration to main-stage operation was an increase in oxidizer pump radial vibration to 75- to 100-g peak during all firings except 40A, where the peak was 45 g.

4.4.3 Steady-State Strain Levels and Engine Vibration at Main-Stage Conditions

Main-stage levels of fuel line strain showed a distinctive trend with propellant utilization valve position with higher steady-state strain at 5.5 mixture ratio, approximately 1200 μin./in. on both the upper and lower fuel line sections at the t_0 + 30-sec data time intervals. The upper fuel line radial strain gage was inoperable during test 41, failing to either calibrate or deflect. Indicated strain increased from 1190 to 1725 μin./in. (14-percent overrange) at the end of firing 40D. The 1725-μin./in. recording is believed to have been invalid, indicating failure of the strain gage.

Oxidizer line strain levels during main-stage operation were typically small, ranging from -155 μin./in. at the upstream tangential location to 105 μin./in. at the downstream tangential location and showed no discernible trend with propellant utilization valve position. The oxidizer line strain gages recorded a shift to the above range of strain values from -340 to -540 μin./in. at engine start for the test 40 firings and from +250 at engine start changing to -205 μin./in at t_0 for firing 41A. These negative-changing-to-positive and then returning-to-negative strain levels at the upstream tangential location indicate flexing of the oxidizer line during a firing; however, a detailed analysis of this flexion is beyond the scope of this report.

Oxidizer pump radial vibration showed a definite trend with propellant utilization valve position, exhibiting typical amplitudes of 100 to 105 g for valve open position during firings 40C and 40D, 90 g for null valve position during firing 40AA, and 60 to 65 g for closed propellant utilization valve position during firings 40AA and 40C. Unusually high oxidizer pump vibration levels of 70 to 75 g were recorded during firings 41A and 41B. There was no apparent effect on oxidizer line steady-state strain from these differences in oxidizer pump vibration.

4.4.4 Propellant Line Vibration Modes

Strain-gage oscillations indicated propellant line vibration occurring at several frequencies as determined from power spectral density analysis. Four data intervals were chosen for analysis from firings 41A and 41B. The results of this analysis are presented in Table IX. The data were analyzed as outlined in Appendix V. Insufficient time duration of stationary high amplitude levels during the oxidizer dome prime and t_0 + 2-sec transient periods precluded electronic wave analysis; however, manual checks of oscillogram data were performed. The following observations are made about the data:

1. Components at 3, 32, and 62 Hz (approximate frequencies) appear to be relatively small fuel line resonance modes.
2. Relatively insignificant components of 18, 26, and 184 Hz (approximate frequencies) have also appeared on the engine accelerometers and are considered to be engine resonance frequencies as installed in the J-4 cell.
3. Components at 300, 400, 460, and 920 Hz (approximate frequencies) appear to be resonance modes associated with the augmented spark igniter, with 460 Hz common to both the fuel and the oxidizer line, 920 Hz the first harmonic of 460 Hz, 400 Hz appearing as a fuel line resonance mode, and 300 Hz appearing as an oxidizer line resonance mode.
4. Fuel line strain oscillations listed in Table VIII are essentially composed of the 400-Hz mode, which is predominant. Manual checks of the oscillograms show the high amplitude start transient oscillations to be excitation of this 400-Hz mode.
5. Oxidizer line strain oscillations listed in Table VIII are essentially composed of the 300-Hz mode, which is predominant. Manual checks of the oscillograms show the high amplitude start transient oscillations to be excitation of this 300-Hz mode.

4.5 FROST FORMATION ON THE AUGMENTED SPARK IGNITER FUEL LINE

Post-flight evaluation testing of the augmented spark igniter fuel line configuration used on the flight AS-502 engines and on engines S/N J-2052 and J-2047 (at AEDC) was conducted by the engine manufacturer at their test facility. Flow-induced high cycle, low amplitude vibration fatigue failures of the flexible bellows sections were produced during a number of tests conducted under dry vacuum conditions simulating 90, 000- to 200, 000-ft pressure altitude. In one test, failure occurred after 22 sec of sustained 200-fps flow. Conclusions drawn from the flexible line flow tests (see Ref. 3) were that two conditions were required to damage and fail the augmented spark igniter fuel line:

1. A fuel flow rate of 1.1 lb_m/sec which produced resonance response in the NA5-260035 single-ply bellows assembly, and
2. A vacuum (nonprotecting) environment.

It was further concluded that liquefaction of air on the outside of the bellows (caused by the cold condition of liquid hydrogen flowing through

the bellows) resulted in both fluid damping of the high amplitude oscillations as well as changing of the fluid/structural coupling of the assembly for sea-level testing operations.

Inasmuch as engine S/N J-2047 had been operated many times in Test Cell J-4 for 15- to 20-sec periods of operation exceeding the 230,000-lb_f-thrust level, a secondary test objective related to the AS-502 flight results was performed during tests 40 and 41. This objective was to determine in a qualitative manner the extent of frost formation on the augmented spark igniter fuel line in the J-4 simulated altitude environment. Bellows resonance amplification in the upper fuel line section induced by the liquid hydrogen flowing within at over 200 fps and the space environment were apparently the two factors that produced the two AS-502 engine malfunctions. Fluid velocities of 200 fps or greater become probable in the 0.5-in.-diam upper line bellows section for 230,000-lb_f-thrust-rated engines because of the higher fuel pump discharge pressure and corresponding higher augmented spark igniter fuel weight flow. More than enough time, over 335 sec, of 230,000-lb_f-thrust operation had been accumulated on engine S/N J-2047 to exceed the bellows fatigue (endurance) limit if bellows resonance amplification had been taking place. Thus, an understanding of the J-4 cell environment would possibly reveal why there had been no failure on engine S/N J-2047.

A color motion-picture camera was installed to obtain a closeup view of the augmented spark igniter fuel line on engine S/N J-2047 during tests 40 and 41, in order to study the ambient environment for the line. Although the optical data were acquired on the newly modified fuel line, these data relate to the original configuration line in that line surface temperatures and fuel flow rates were approximately the same. The optical data, Fig. 71, taken during test 41 revealed that significant frost accumulation occurs in the J-4 cell environment.

The optical data revealed that the frost deposit was present at engine start for each firing; thus, it occurred during helium prechilling of the thrust chamber. Considering firing 41A as an example, having maximum augmented spark igniter fuel flow, the augmented spark igniter fuel line temperature was -70°F at engine start. Test cell pressure during thrust chamber prechill operations was approximately 1 psia until the steam ejector was started, lowering the cell pressure to 0.15 psia (or 102,000 ft). Cell pressure averaged about 0.2 psia (or 95,000 ft) throughout the firing (Fig. 54). The line surface temperature was such that only water vapor from the cell atmosphere formed the initial frost layer. Chilldown of the fuel line, as liquid hydrogen flow was established through the line, produced a steady-state level of approximately -390°F after t_0 + 9 sec.

There was no evidence in the optical data of increasing frost layer thickness on the fuel line, the fuel manifold, or the main fuel valve during main-stage operation of firing 41A or any of the subsequent test 41 firings. Neither was any liquid droplet formation observed during any of the firings. However, these are strictly qualitative judgments based only on viewing of the film. The J-4 cell atmosphere is composed of approximately 96-percent nitrogen (minimum) as a result of the inerting purge. The triple-point conditions for nitrogen are 1.818 psia and -346°F (Ref. 9). Thus, atmospheric pressure and nitrogen partial pressure remained well below triple-point pressure precluding liquid nitrogen condensation on any of the cold hydrogen system components. Apparently, there was insufficient oxygen content (less than 4 percent by volume) for liquid oxygen condensation to be visible during chilldown, oxygen triple-point conditions are 0.022 psia and -362°F (Ref. 9).

Following engine cutoff, during facility steam ejector shutdown, the frost was dislodged from the fuel manifold (Fig. 71c) by blowback gas flow from the diffuser until the differential pressure between the spray chamber and test cell was nullified. When cell pressure rises above nitrogen triple-point pressure several seconds after cutoff, nitrogen condensation as liquid on cold hydrogen surfaces then becomes possible. This phenomenon has been observed routinely in the closeup television views around the top of the engine while nitrogen is being introduced to the cell during post-fire repressurization but was not evident on the lower augmented spark igniter fuel line in the film.

The liquid-air formation on cold hydrogen surfaces that occurs during sea-level static testing cannot occur in the J-4 altitude environment; thus, the fluid-damping protection mechanism described in Ref. 3 is not possible. But the J-4 environment does not simulate the dry-vacuum environment of space flight or the dry-gaseous nitrogen engine interstage compartment environment before engine start for this engine component. Therefore, artificial protection from the engine ambient environment may have been a factor, if the frost formation could offer protection.

Reference 3 reports that one pit test series was conducted to determine the effect of moisture-only cryodeposit on the bellows. Helium gas saturated with water vapor was the environment used. Failures occurred at the resonance flow rate in the frost-only environment as in the dry-vacuum environment tests (from approximately 90,000- to 200,000-ft simulated pressure altitude). It was concluded in Ref. 3 from these tests that moisture in the air alone during sea-level testing could not adequately protect the bellows from failure.

In order to attempt an answer to the question of why there was no failure of the augmented spark igniter fuel line on engine S/N J-2047 after uprating to 230,000 lb_f-thrust, the NA5-260035 upper line section removed from the engine before test 39 was given cursory examination. The old line section was cut off from the injector inlet tube immediately downstream of the weld by which it had been joined to the igniter assembly and is shown in Fig. 72. The internal dimensions of the line were checked with the following results:

0.406-in. Internal Diameter, Tube and Instrumentation Block, Bore

0.453-in. Internal Diameter, Bellows Convolutions

However, examination of the welds at each end of the flexible hose section yielded an unexpected result. The internal surface of the tube at the upstream weld, joining the hose to the instrumentation block, was relatively smooth, presenting no appreciable area reduction. However, the downstream weld partially closed the line, as shown in Fig. 72b. This amount of area reduction by weldment would have essentially acted as an orifice, increasing the pressure drop of the overall fuel line and decreasing the flow rate. A dimensional check at the weld location revealed diameters from 0.278-in. minimum to 0.333-in. maximum and an average of four diameters equal to 0.308 in. It is possible that this weld may have maintained the line flow rate below the 1.1-lb_m/sec resonance level, thereby precluding a bellows failure on this engine during testing in the J-4 cell.

4.6 ENGINE STEADY-STATE PERFORMANCE

Engine steady-state performance data are presented in Table X for a 1-sec data average between 29 and 30 sec after t_0 for firings 39A, 40AA, 40C, and 41A. These data were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine input data required by the program and the programmed equations are presented in Appendix VII. The gas generator outlet temperature (TGGO-1A) was used for calculations throughout this series of tests in place of the fuel turbine inlet temperature (TFTI-1P).

The engine was reorificed between tests J4-1801-39 and -40, replacing the 1.541-in.-diam oxidizer turbine bypass valve orifice with one of 1.430-in. diameter, to obtain maximum engine performance. A significant increase of nearly 7000 lb_f in calculated engine thrust occurred on firings 40AA and 40C as compared to firing 39A. The engine

was again reorificed (see Table III) between tests J4-1801-40 and -41 to return performance to nominal conditions. The calculated engine thrust of 227,733 lb_f on test 41 was a decrease of approximately 4100 lb_f as compared to firing 39A.

4.7 START TANK REFILL

The start tank is refilled with hydrogen from a tapoff at the fuel injection manifold and through the start tank topping line that tees from the augmented spark igniter fuel supply line and contains a topping flow orifice (Fig. 4). At approximately t_0 + 5 sec, start tank pressure exceeds that of the fuel injector, thus allowing only the start tank topping line to continue the refilling process (Ref. 10).

Start tank refill data for six 32.5-sec firings are presented in Fig. 73. Between tests J4-1801-39 and -40 a larger (0.070-in.-diam) topping line orifice was installed, replacing the smaller 0.054-in.-diam orifice. The larger orifice allowed the start tank to be refilled at lower temperatures (by approximately 30°F after 30 sec of engine operation) and at a faster rate than could be obtained using the smaller orifice.

4.8 POST-TEST INSPECTION

4.8.1 Test J4-1801-39

The augmented spark igniter ignition detect probe failed during firing 39E. The probe was replaced before test period J4-1801-40. Integrity of the augmented spark igniter propellant lines was satisfactory.

Extremely high chamber pressure at oxidizer dome prime during test 39D motivated inspection of the injector for possible cracked posts. Vacuum check of the injector indicated it to be within specifications.

The engine gimbal bearing was inspected for wear. A dimensional check revealed the bearing to be within specified tolerances, although approaching the maximum limit for wear.

4.8.2 Test J4-1801-40

The augmented spark igniter ignition detect probe failed during firing 40D and was replaced before test period J4-1801-41. Post-test visual inspection of the augmented spark igniter revealed that no

discoloration or erosion had occurred. Integrity of the augmented spark igniter assembly was satisfactory.

4.8.3 Test J4-1801-41

The augmented spark igniter ignition detect probe failed during firing 41D. Augmented spark igniter assembly integrity was satisfactory.

Test J4-1801-41 was the final test at AEDC on engine J-2047, and removal of the engine followed this test.

SECTION V
SUMMARY OF RESULTS

The results of the 14 firings of the J-2 engine (S/N J-2047) conducted during test periods J4-1801-39 through -41, using modified augmented spark igniter propellant lines, are summarized as follows:

1. Augmented spark igniter operation was satisfactory during all of the firings. Significant observations about the ignition transients were:
    a. Longer ignition detection delay time (up to 3.542 sec, firing 39A) and cooler igniter chamber temperatures resulted from maximum fuel pump inlet pressure with minimum oxidizer pump inlet pressure,
    b. Moderate igniter chamber temperatures (300 to 600°F) resulted from maximum oxidizer pump inlet pressure with minimum fuel pump inlet pressure,
    c. High igniter chamber temperature (1200°F) resulted from a combination of maximum oxidizer pump inlet pressure with maximum fuel pump inlet pressure and (1000°F) from minimum fuel pump inlet pressure with minimum oxidizer pump inlet pressure for 8-sec fuel lead starts, and
    d. Higher igniter chamber temperatures resulted from 8-sec fuel lead starts compared to 3-sec fuel lead starts, in particular, for very cold thrust chamber starts, with 1500°F the maximum observed (firing 41B).
2. Structural integrity of the interim-configuration augmented spark igniter fuel line and of the Engineering Change Proposal 643 fuel and oxidizer lines was completely satisfactory.

Significant observations about the post-flight AS-502 modification augmented spark igniter propellant line strain and vibration data were:

a. Maximum fuel line strain levels occurred during main-stage operation at 5.5 mixture ratio (upper and lower fuel line sections); both were measured at approximately 1200-μin. strain,

b. A vibration mode at approximately 460 Hz was observed on both the fuel and oxidizer lines. A 400-Hz resonance mode was predominant on the fuel line, reaching ±500 μin./in. and a 300-Hz mode predominant on the oxidizer line, reaching ±104-μin./in. maximum during thrust chamber buildup to main-stage operation, and

c. During vibration safety count periods at oxidizer dome prime, peak oscillatory levels of from ±720- to ±930-μin./in. strain were recorded on the upper fuel line section and ±290- to ±365-μin./in. strain were recorded on the oxidizer line.

3. As a secondary test objective related to the engine failures that occurred on flight AS-502, closeup color motion-picture data revealed the presence of frost deposited on the augmented spark igniter fuel line, indicating the possibility that artificial protection of the original fuel line bellows sections may have occurred during previous AEDC tests. However, a line weld near the augmented spark igniter injector may have reduced the flow area sufficiently that critical bellows-resonance flow rates were never achieved on engine S/N J-2047.

4. Thrust chamber pressure buildup characteristics and gas generator temperature transients were consistent with engine starting energy, as observed during previous AEDC testing, with the exception of one very cold thrust chamber start (firing 39D). Firing 39C recorded the lowest gas generator peak temperature for a low energy start to date of only 720°F. Low starting energy and 80-Hz thrust chamber pressure fluctuations (combustion instability) during firing 39D produced a double priming of the oxidizer dome and two close approaches to fuel pump stall, 250- and 400-gpm stall margin, respectively.

5. The increase in start tank topping line orifice size to 0.070-in. diameter, incorporated with the augmented spark igniter fuel line modification, effected an appreciable change in start tank refill characteristics, allowing the start tank to be refilled at lower temperatures (approximately 30°F) and at a faster rate than could be obtained using the smaller orifice.

REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. "Saturn V Launch Vehicle Flight Evaluation Report - AS-502 Apollo 6 Mission." MPR-SAT-FE-68-3, June 25, 1968.
3. "J-2 Engine AS-502 (Apollo 6) Flight Report S-II and S-IVB Stages." R-7450-2, Volumes 2 and 3, June 17, 1968, Volume 4, September 13, 1968.
4. Pillow, C. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-37 and J4-1801-38)." AEDC-TR-68-201, November 1968.
5. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.
6. Test Facilities Handbook (Seventh Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, July 1968.
7. Collier, M. R. and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1554-26)." AEDC-TR-67-145, October 1967.
8. Pollard, F. B. and Arnold J. H., Jr. Aerospace Ordnance Handbook, Prentice-Hall, Inc., 1966.
9. Hilsenrath, J., et al. Tables of Thermal Properties of Gases, National Bureau of Standards Circular 564, November 1, 1955.
10. Muse, W. W. and Franklin, D. E. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-01 through J4-1554-11)." AEDC-TR-67-87, June 1967.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. AUGMENTED SPARK IGNITER CONFIGURATION SUMMARY
V. AUGMENTED SPARK IGNITER DATA REDUCTION
VI. DEFINITIONS OF TERMS
VII. METHOD OF CALCULATIONS (PERFORMANCE PROGRAM)

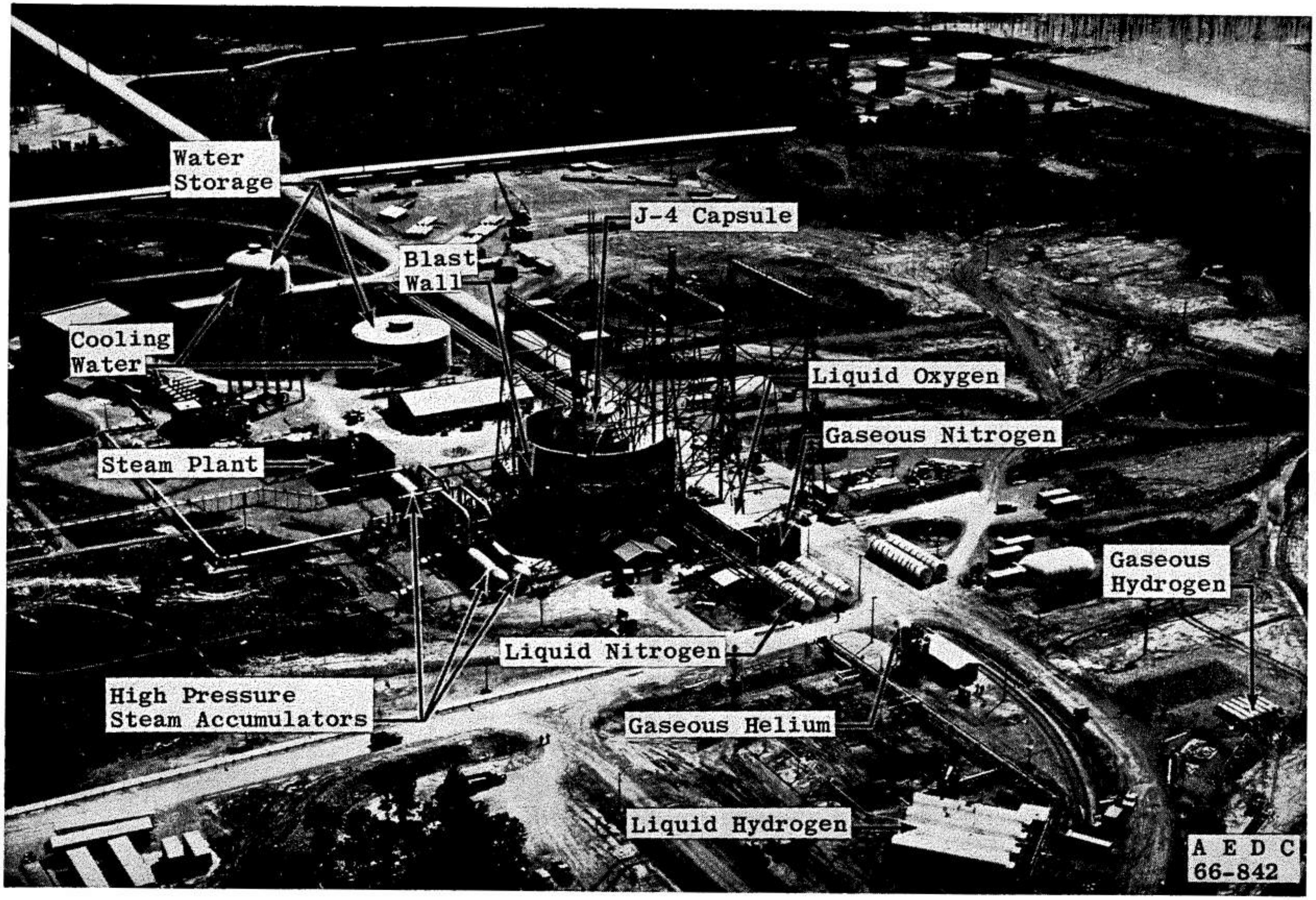


Fig. 1 Test Cell J-4 Complex

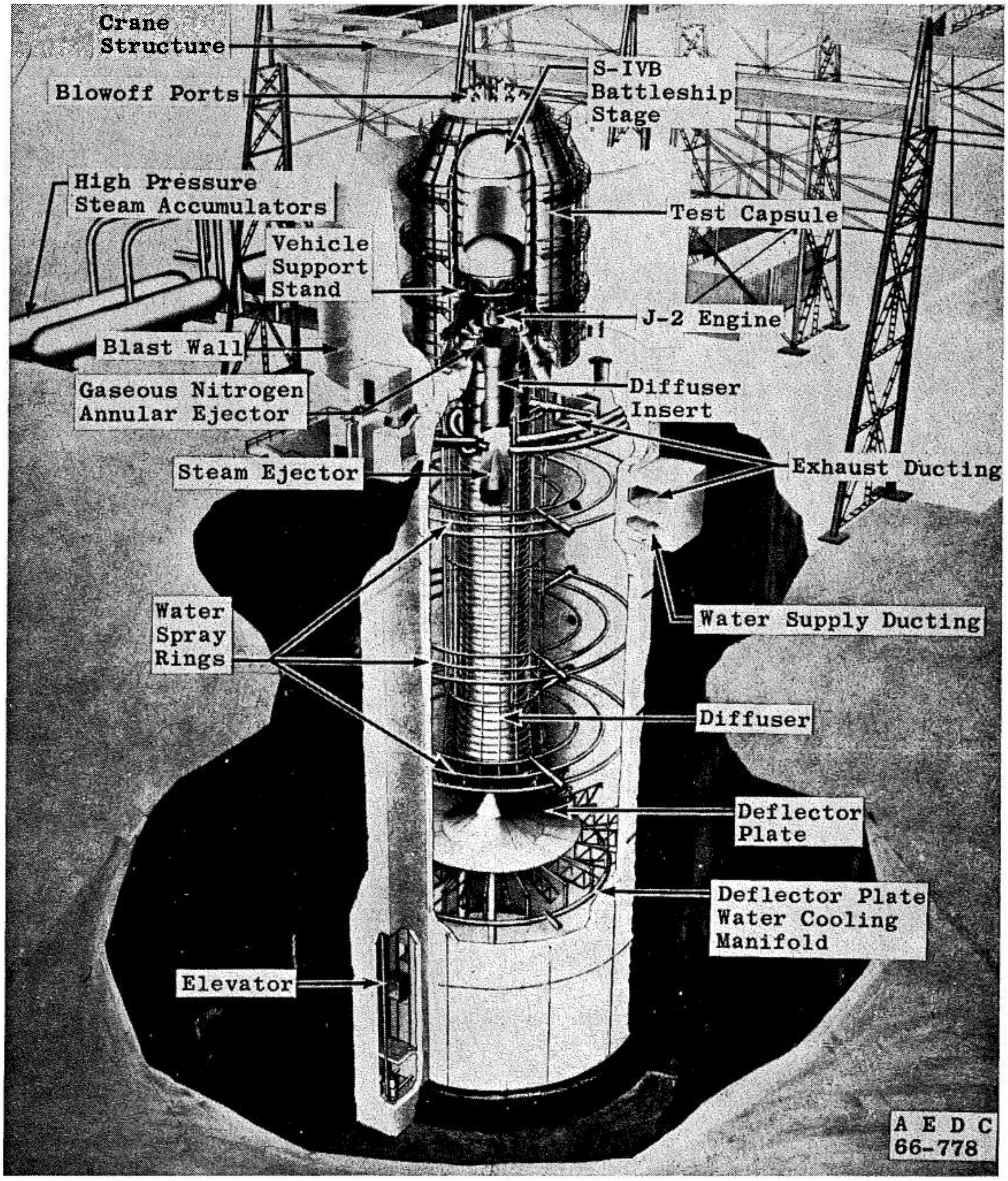
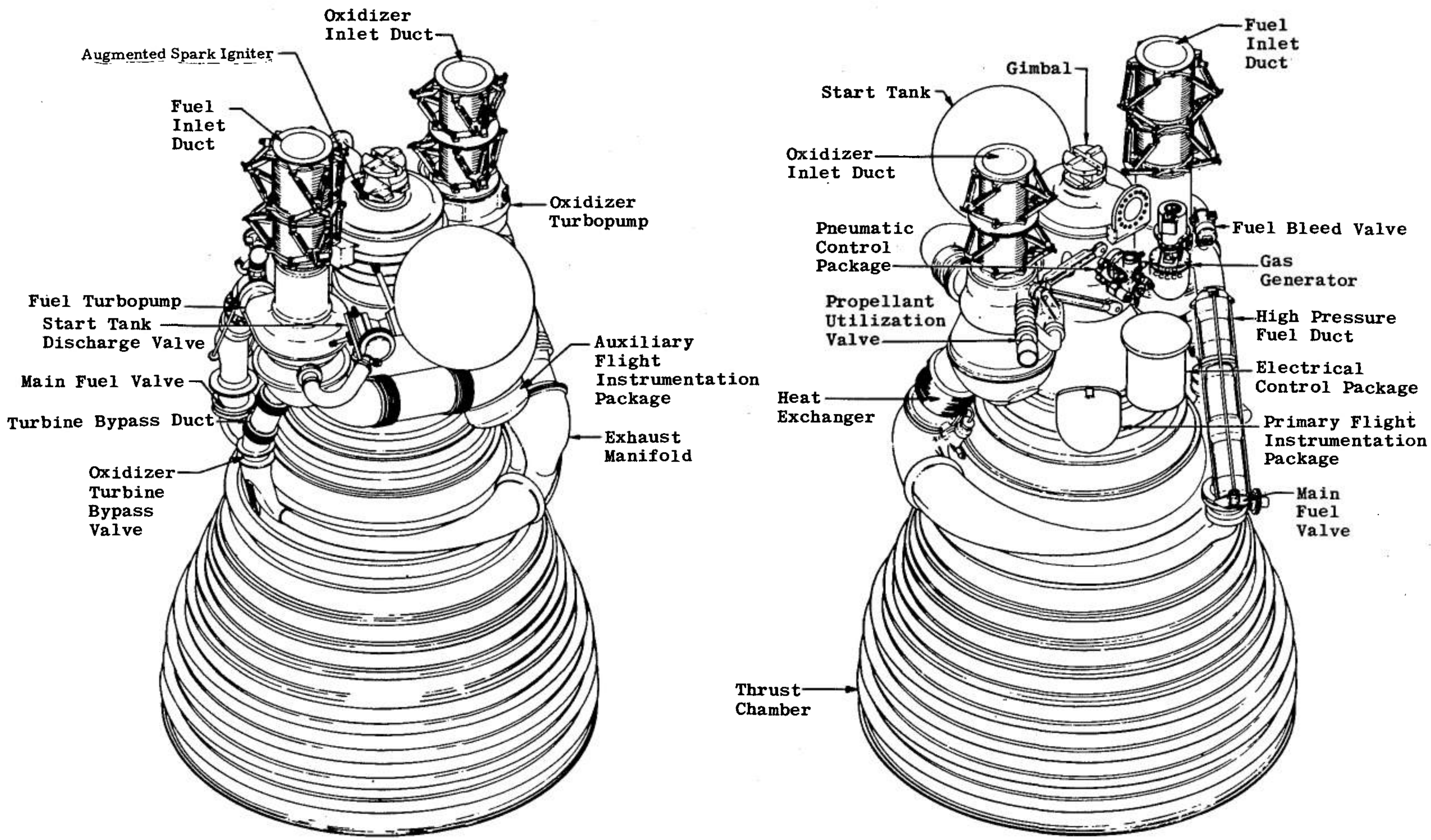
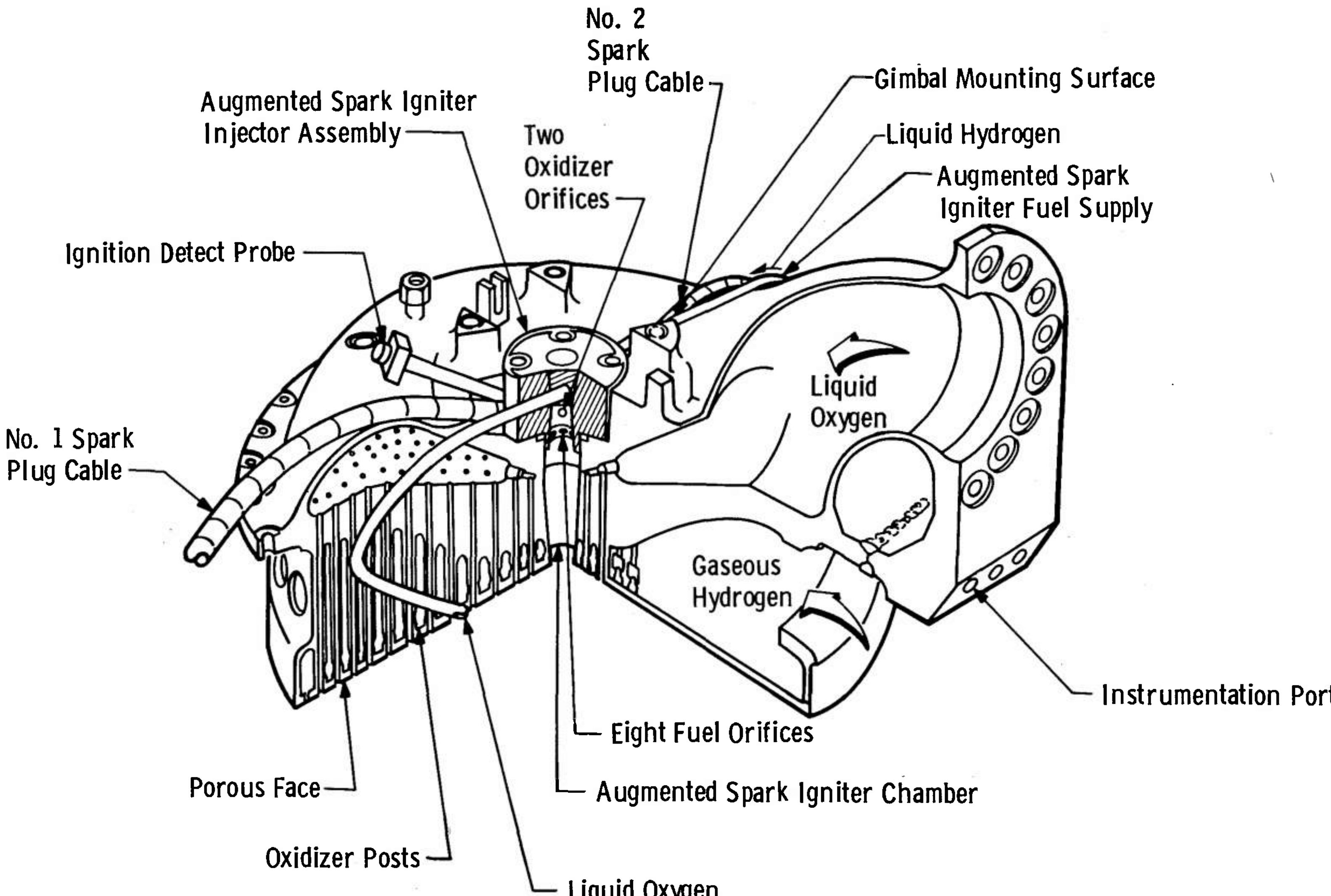


Fig. 2 Test Cell J-4, Artist's Conception



a. Major Engine Component Locations

Fig. 3 Engine Details



b. Details of the Augmented Spark Igniter Assembly and Main Chamber Injector

Fig. 3 Concluded

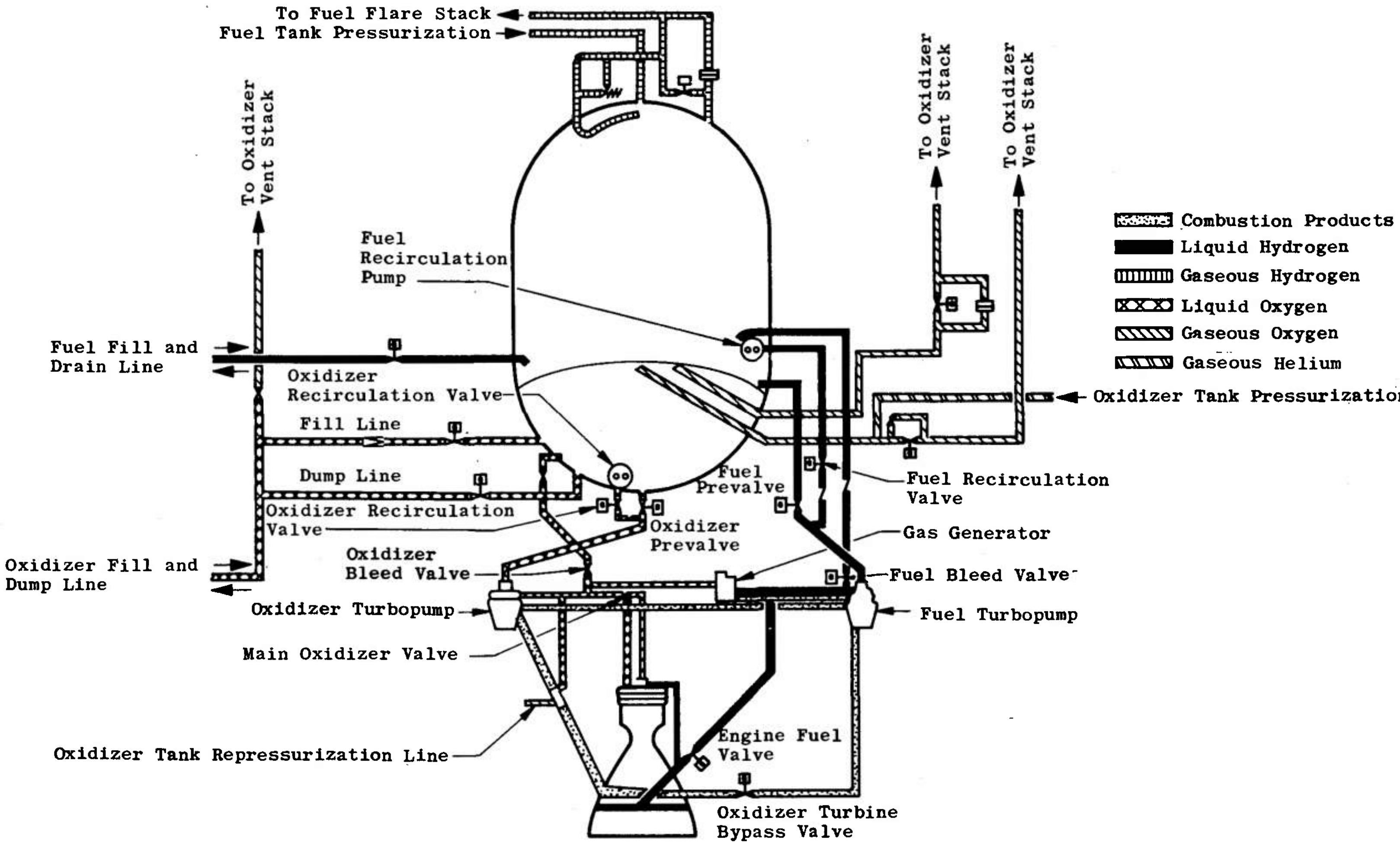


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

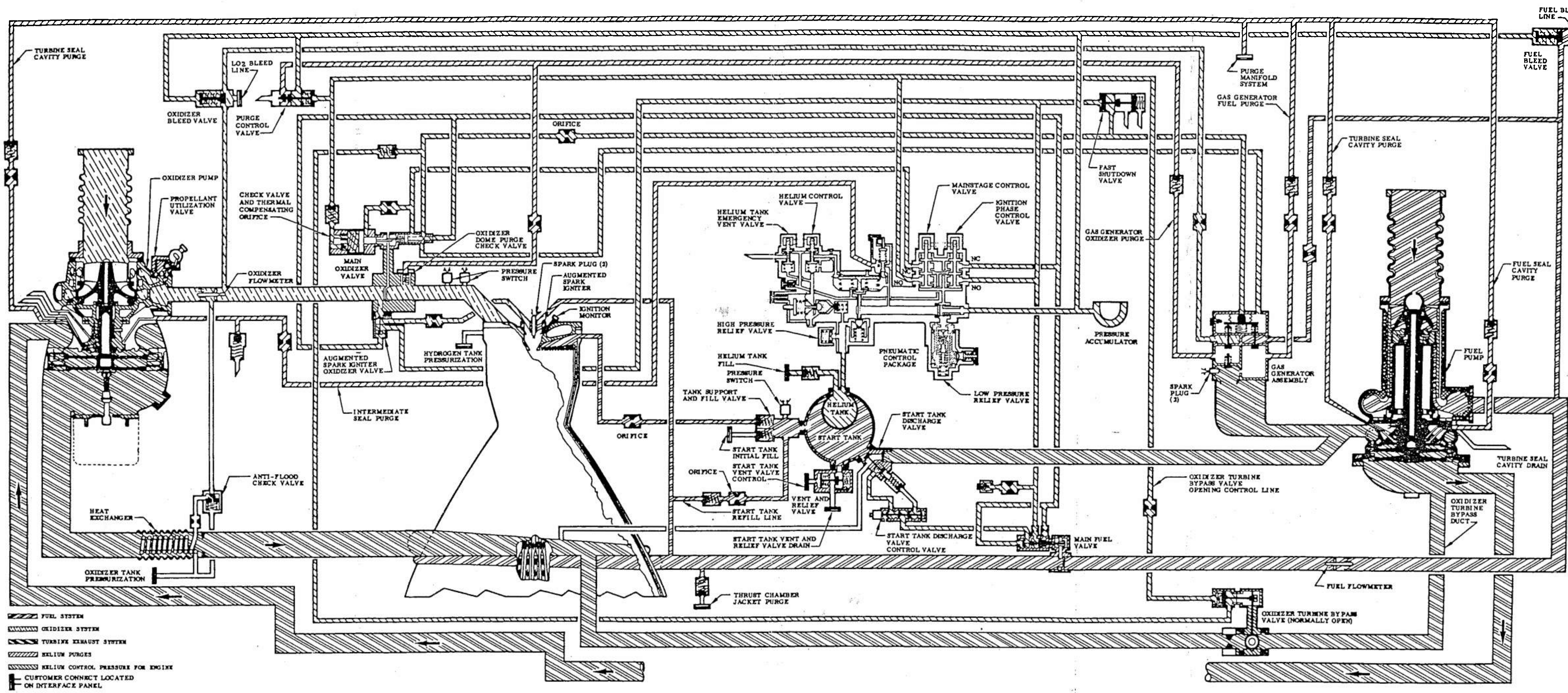


Fig. 5 Engine Schematic

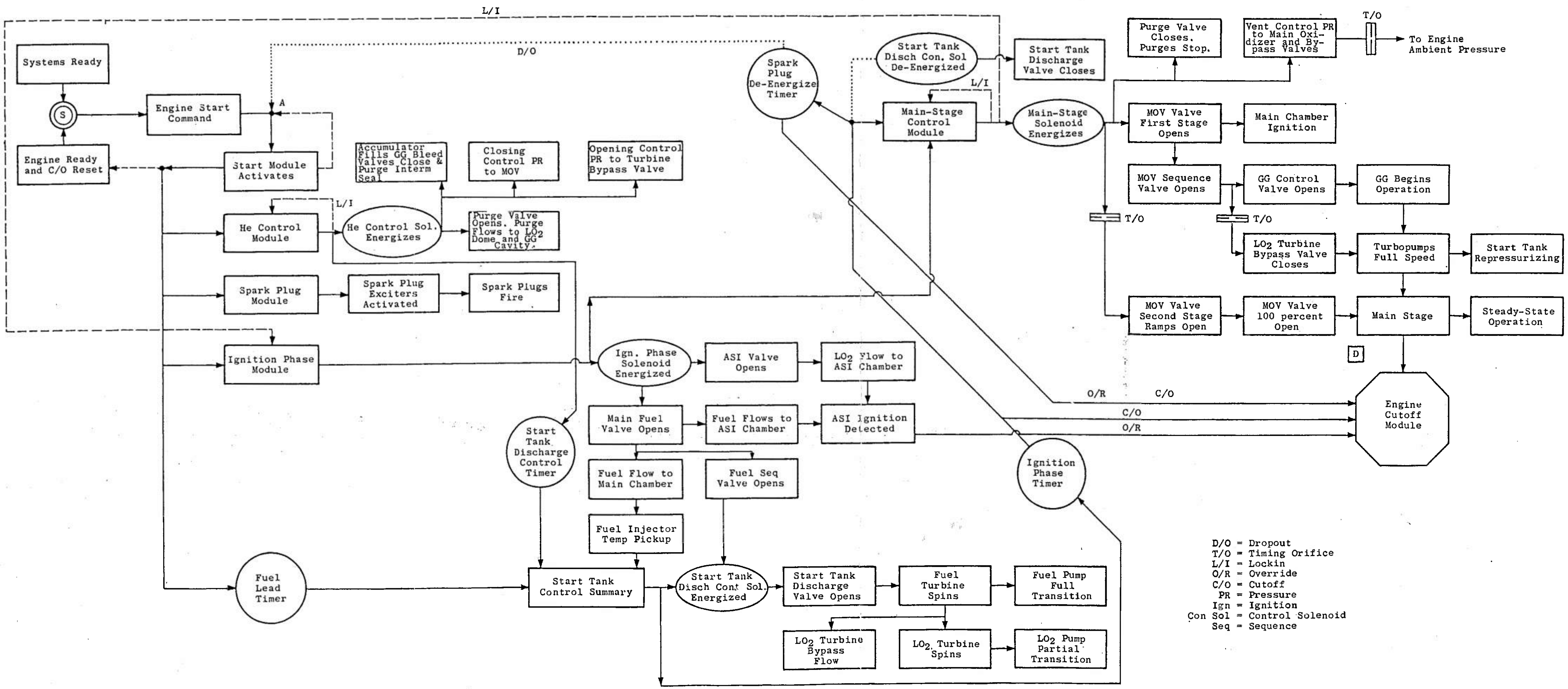
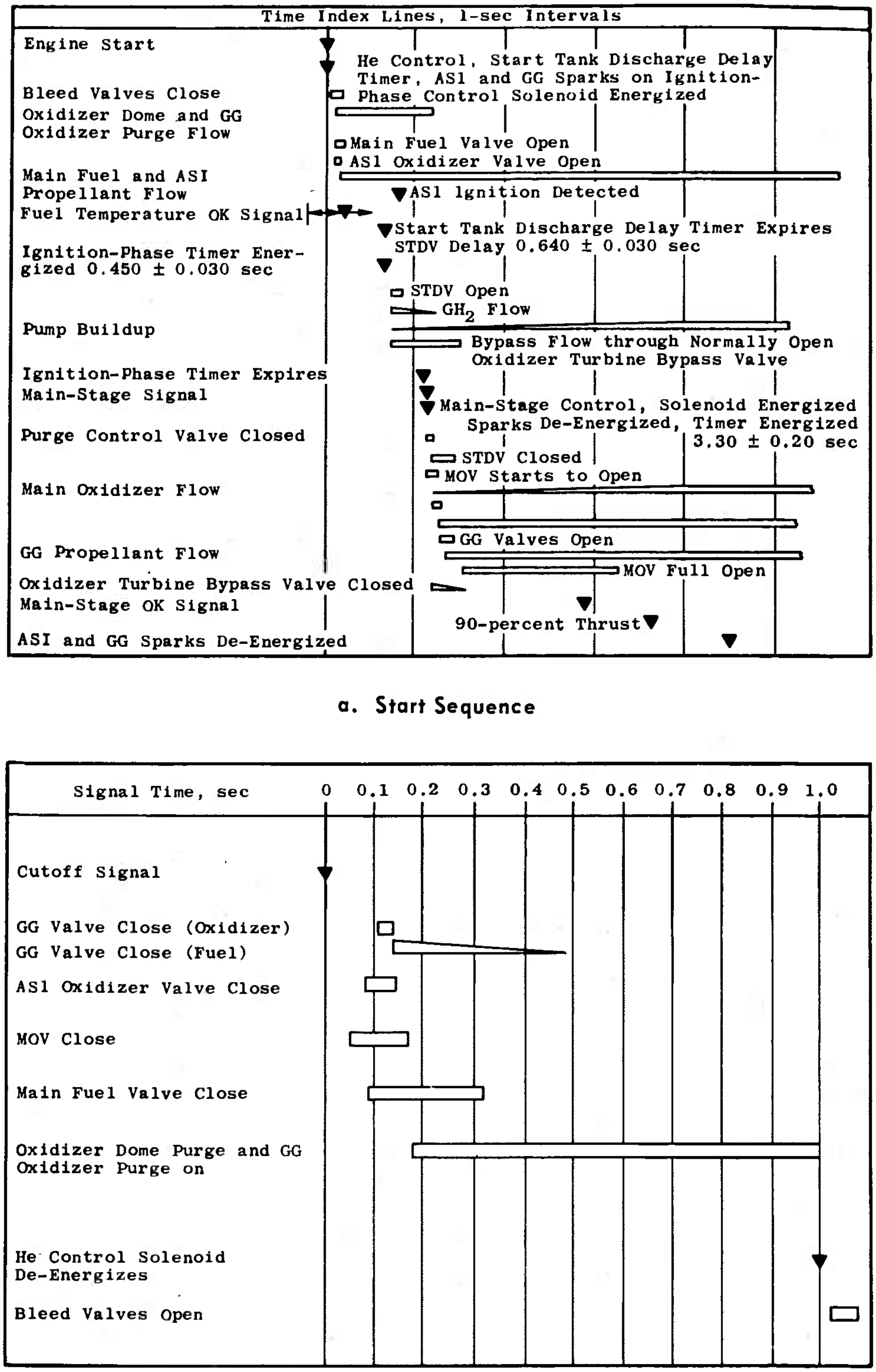


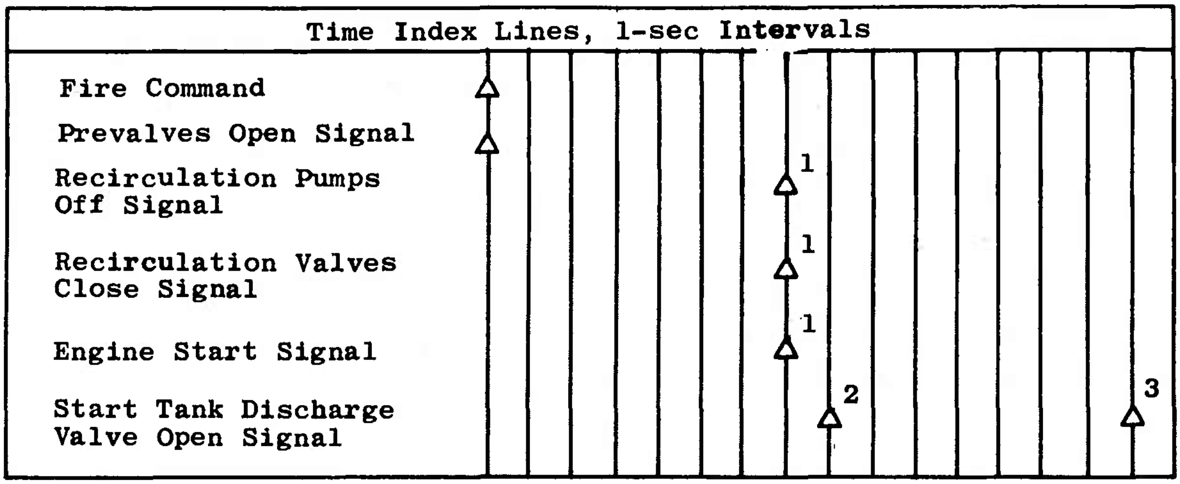
Fig. 6 Engine Start Logic Schematic



a. Start Sequence

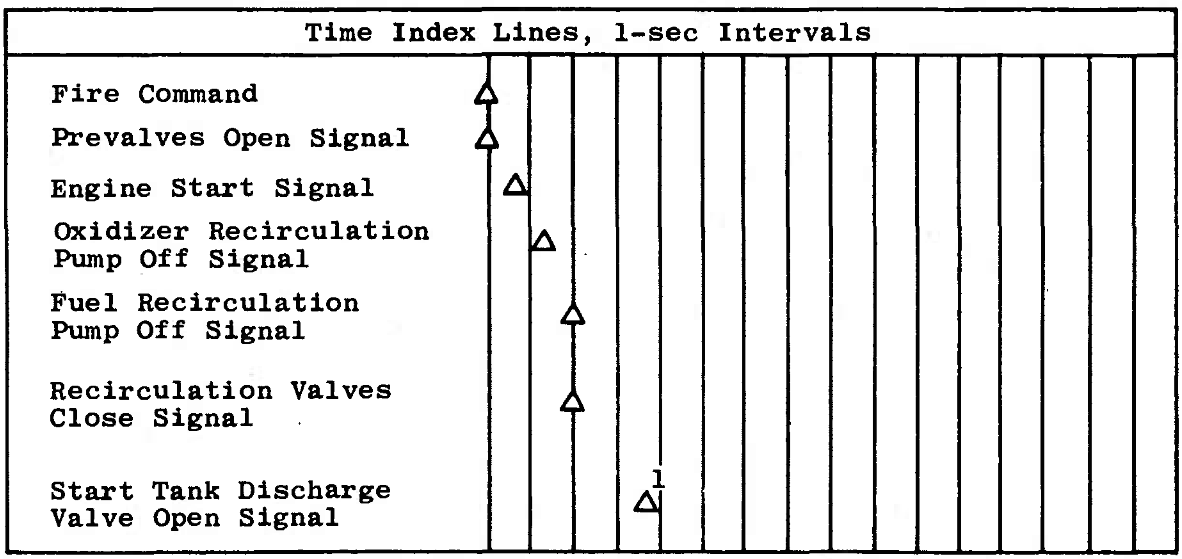
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

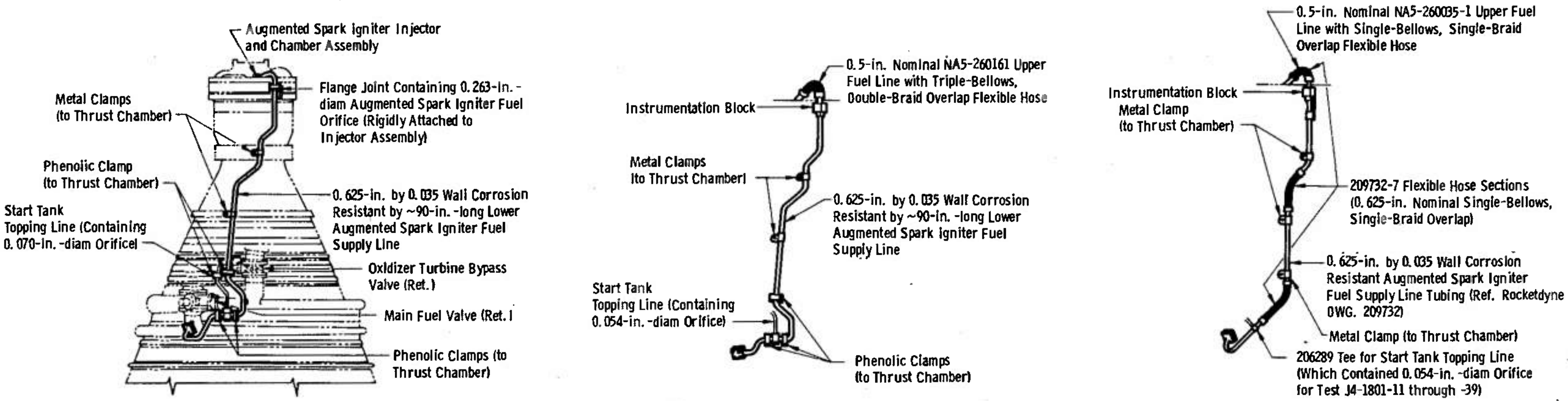
c. "Normal" Start Sequence



[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded



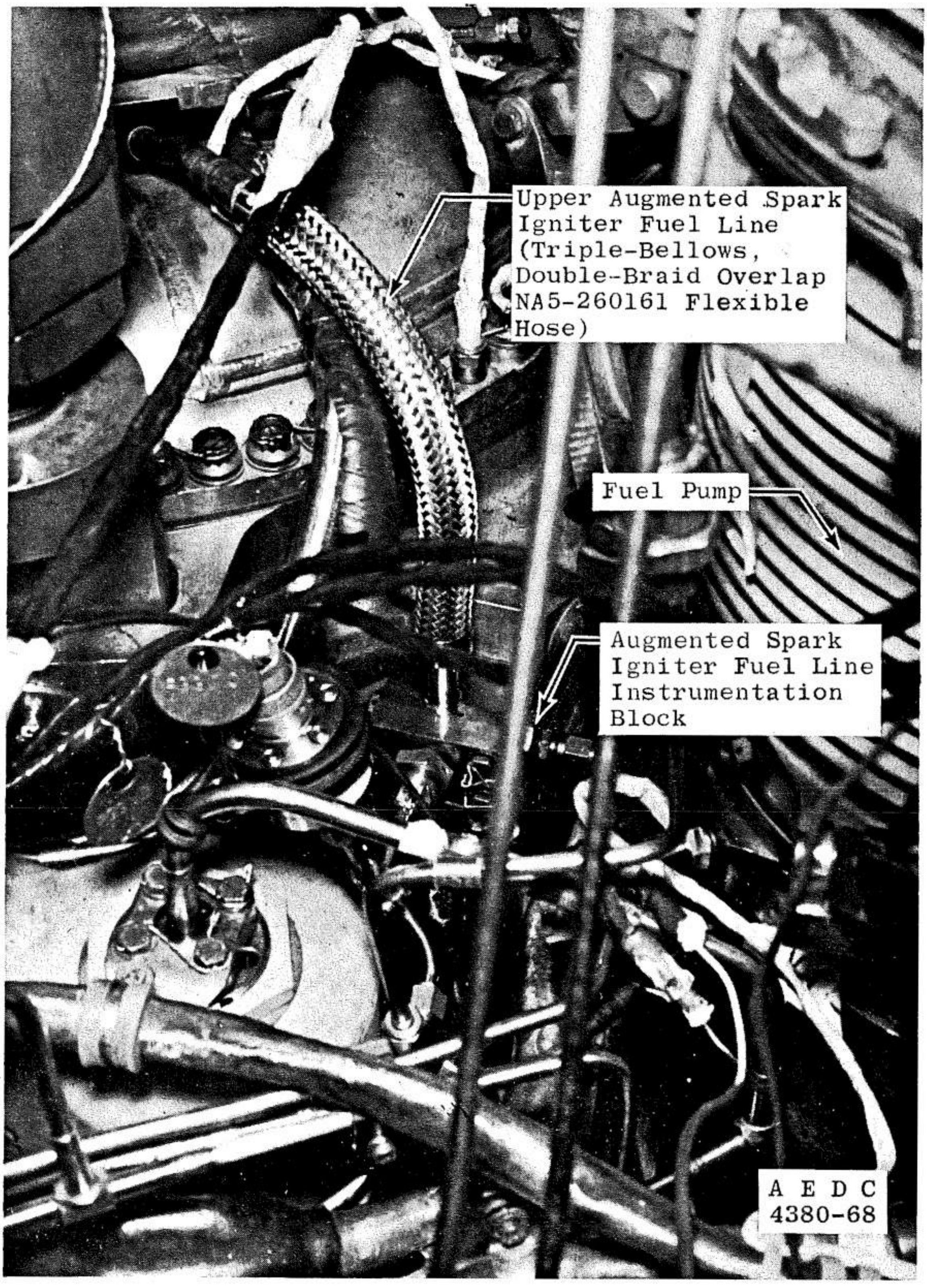
New Augmented Spark Igniter Fuel Supply Line (Tests J4-1801-40 and -41 Configurations)

Interim Augmented Spark Igniter Fuel Supply Line Configuration (Test J4-1801-39, Shown Removed)

Original Augmented Spark Igniter Fuel Supply Line Configuration on J-2047 for AEDC Test Program (Tests J4-1801-11 through -38, Shown Removed)

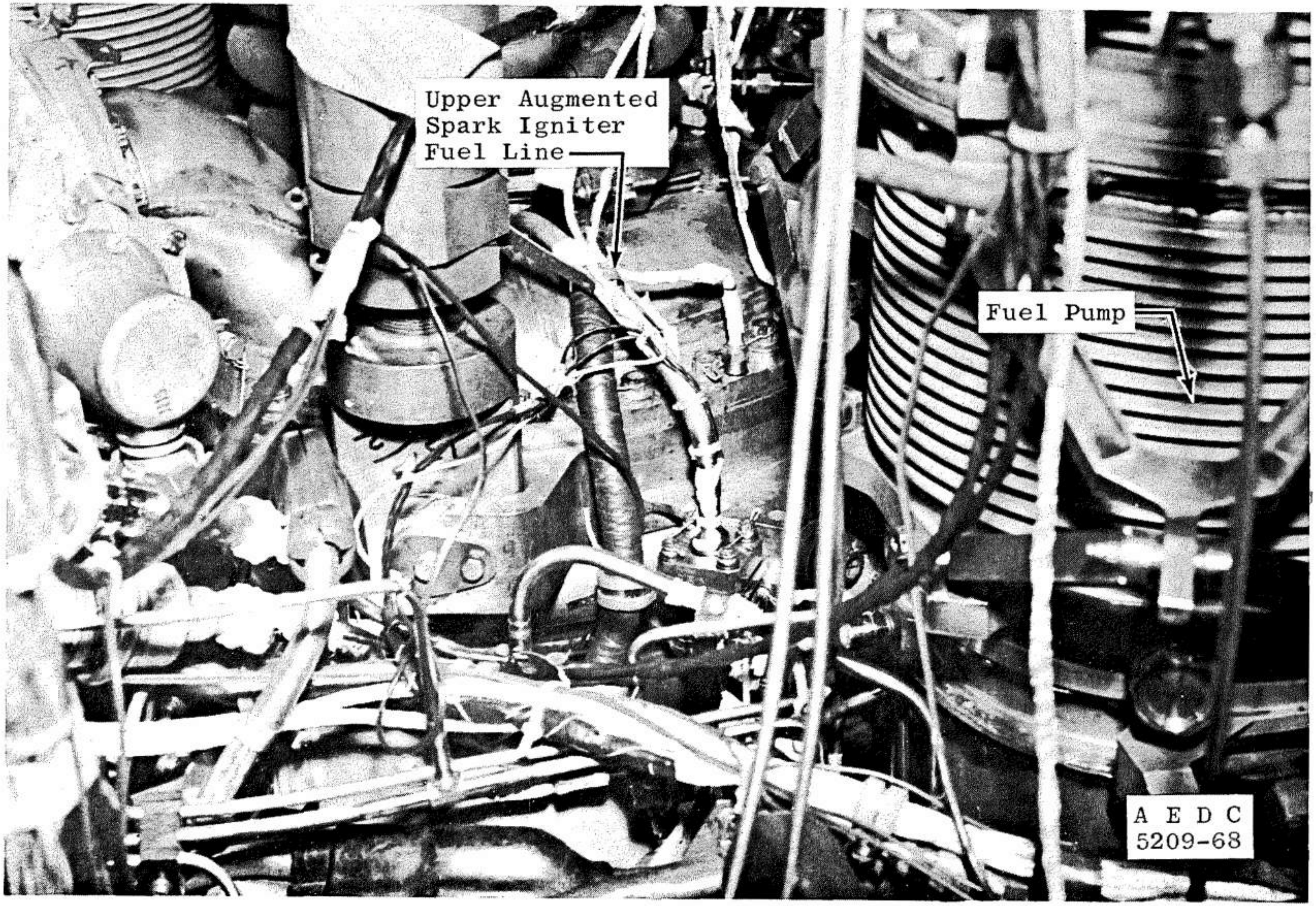
a. Augmented Spark Igniter Fuel Supply Line Configurations

Fig. 8 Augmented Spark Igniter Fuel Supply Line Modifications

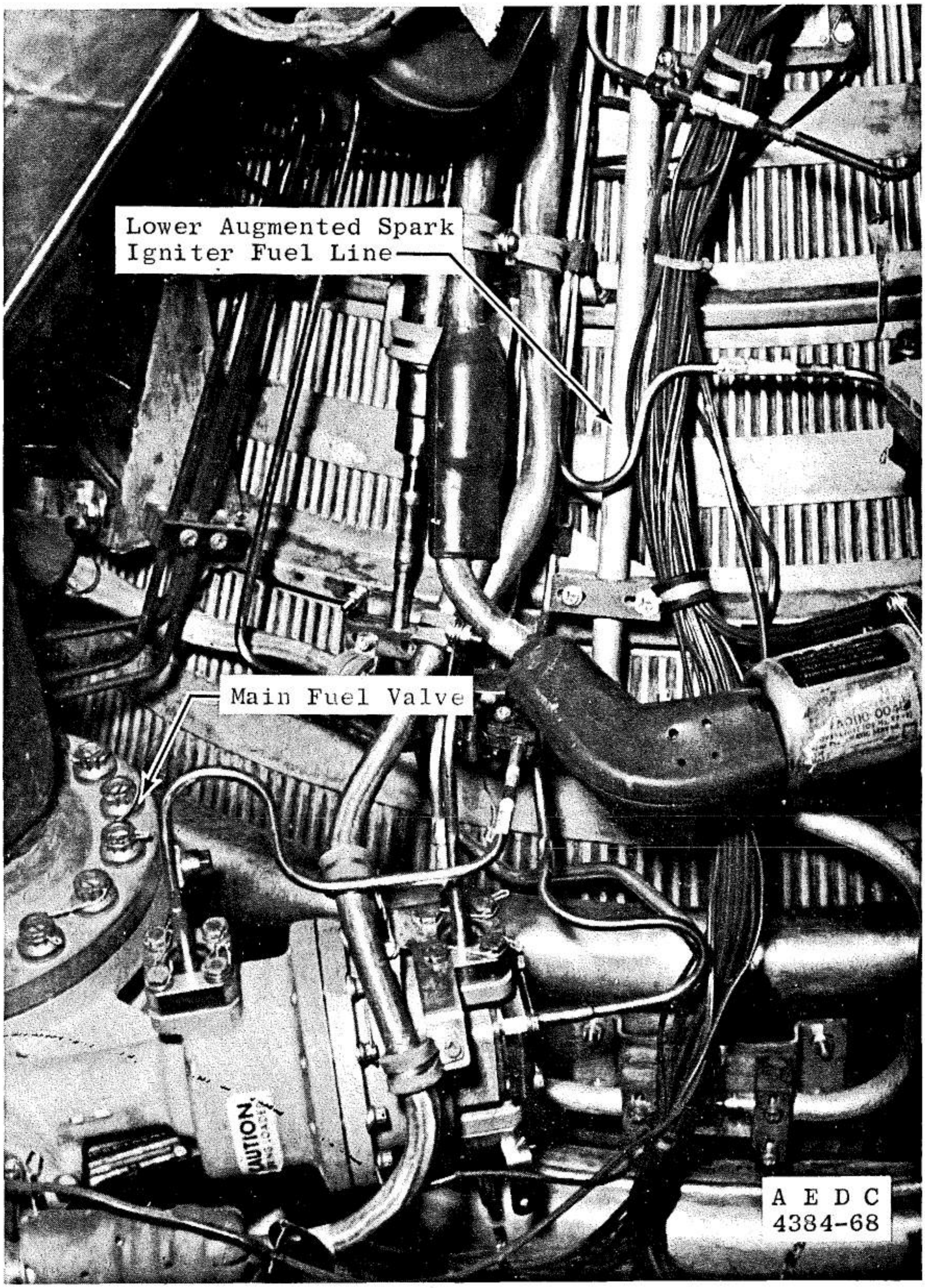


b. Upper Fuel Line Assembly, Interim Configuration

Fig. 8 Continued

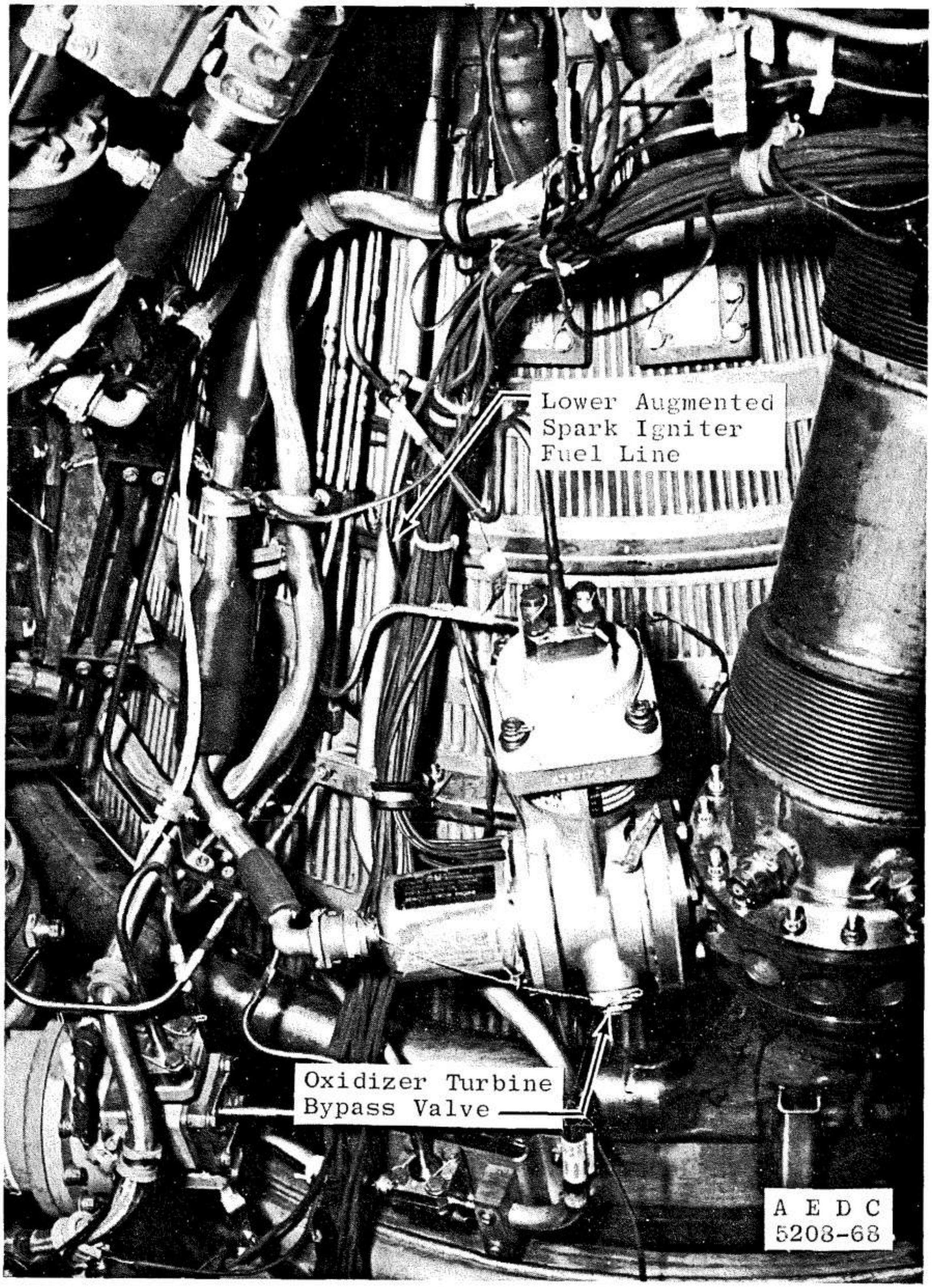


c. Upper Fuel Line Assembly, New Configuration
Fig. 8 Continued



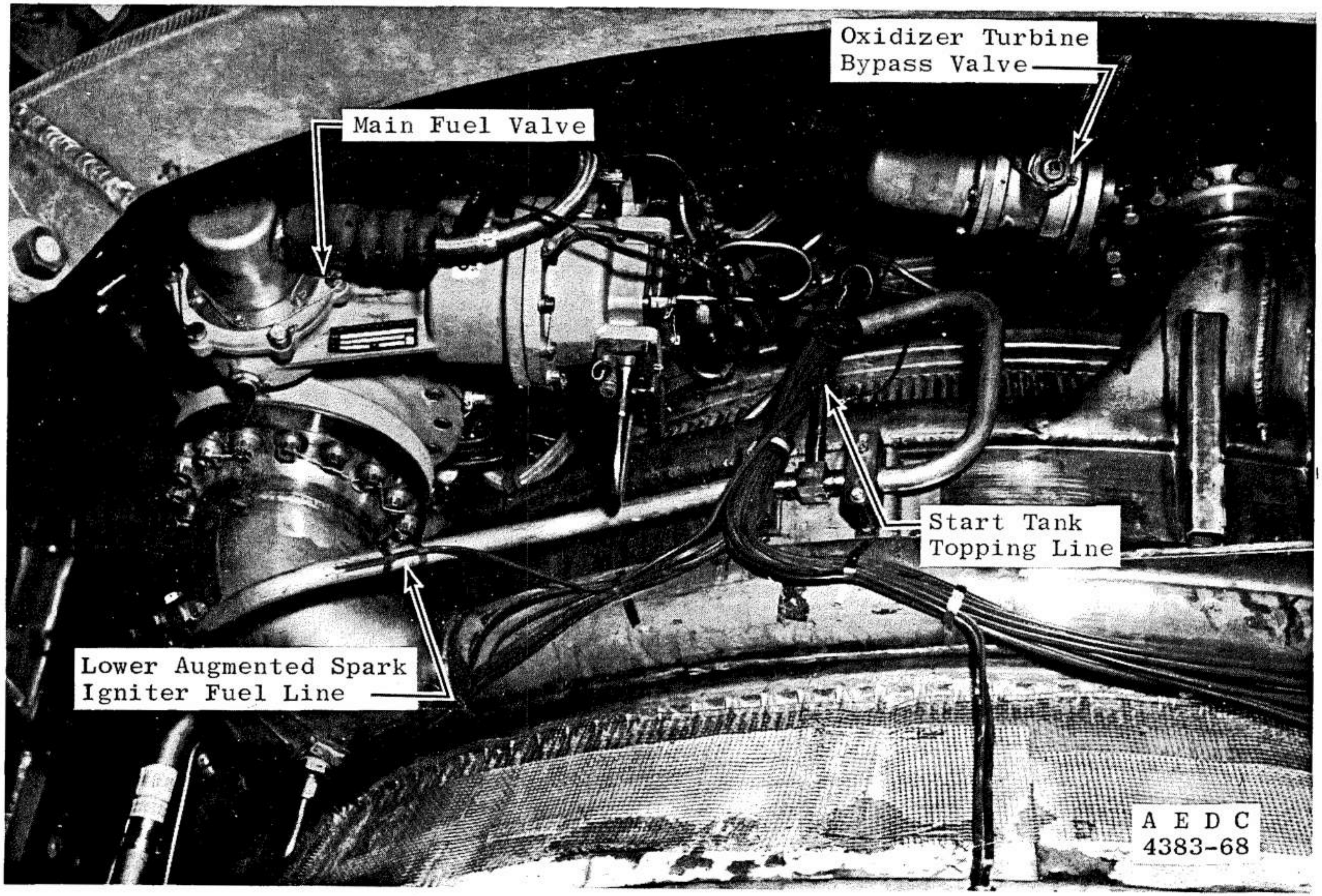
d. Lower Fuel Line Attachment Points to Thrust Chamber, Interim Configuration

Fig. 8 Continued



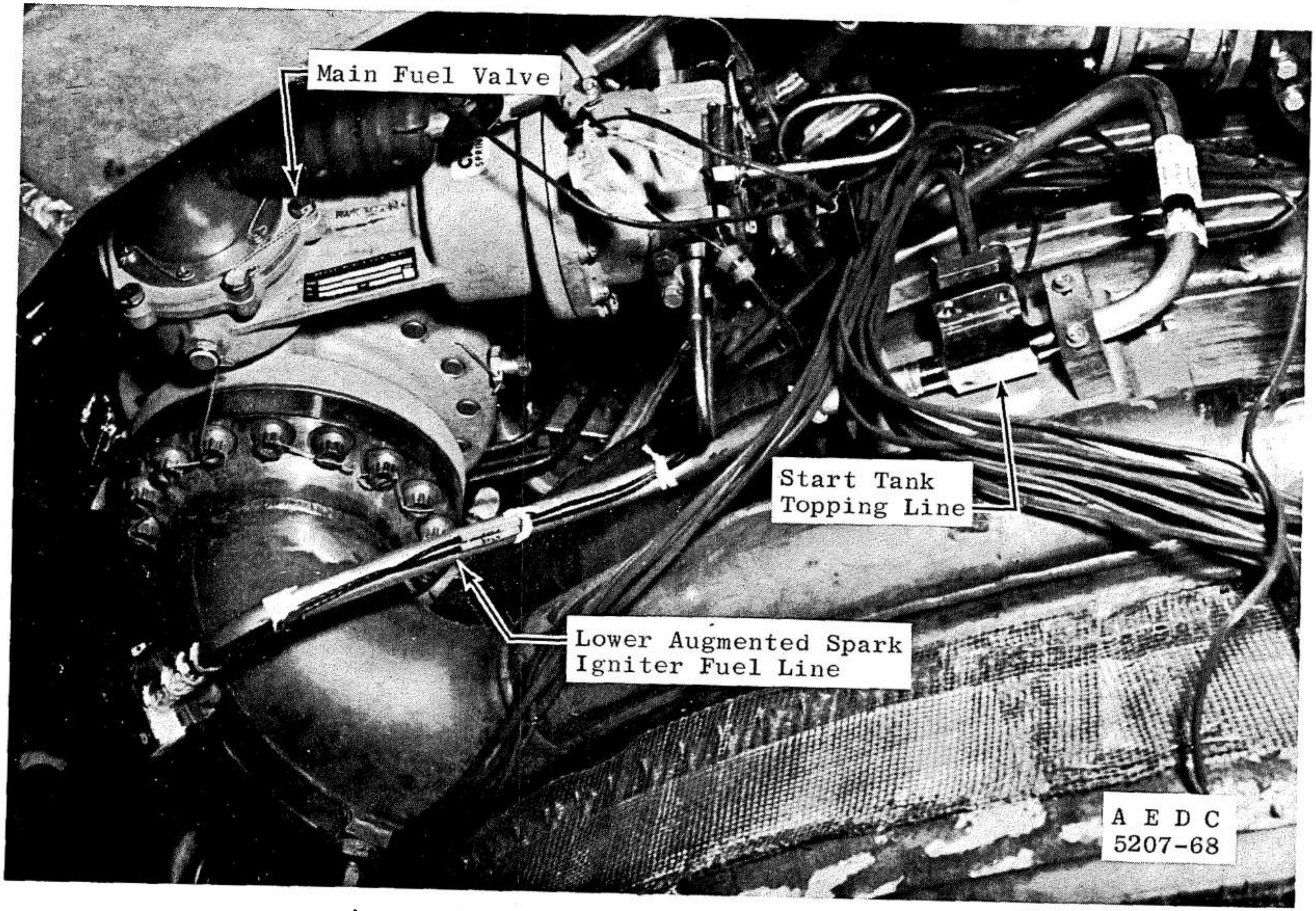
e. Lower Fuel Line Attachment Points to Thrust Chamber, New Configuration

Fig. 8 Continued



f. Lower Fuel Line and Start Tank Topping Line, Interim Configuration

Fig. 8 Continued



g. Lower Fuel Line and Start Tank Topping Line, New Configuration

Fig. 8 Concluded

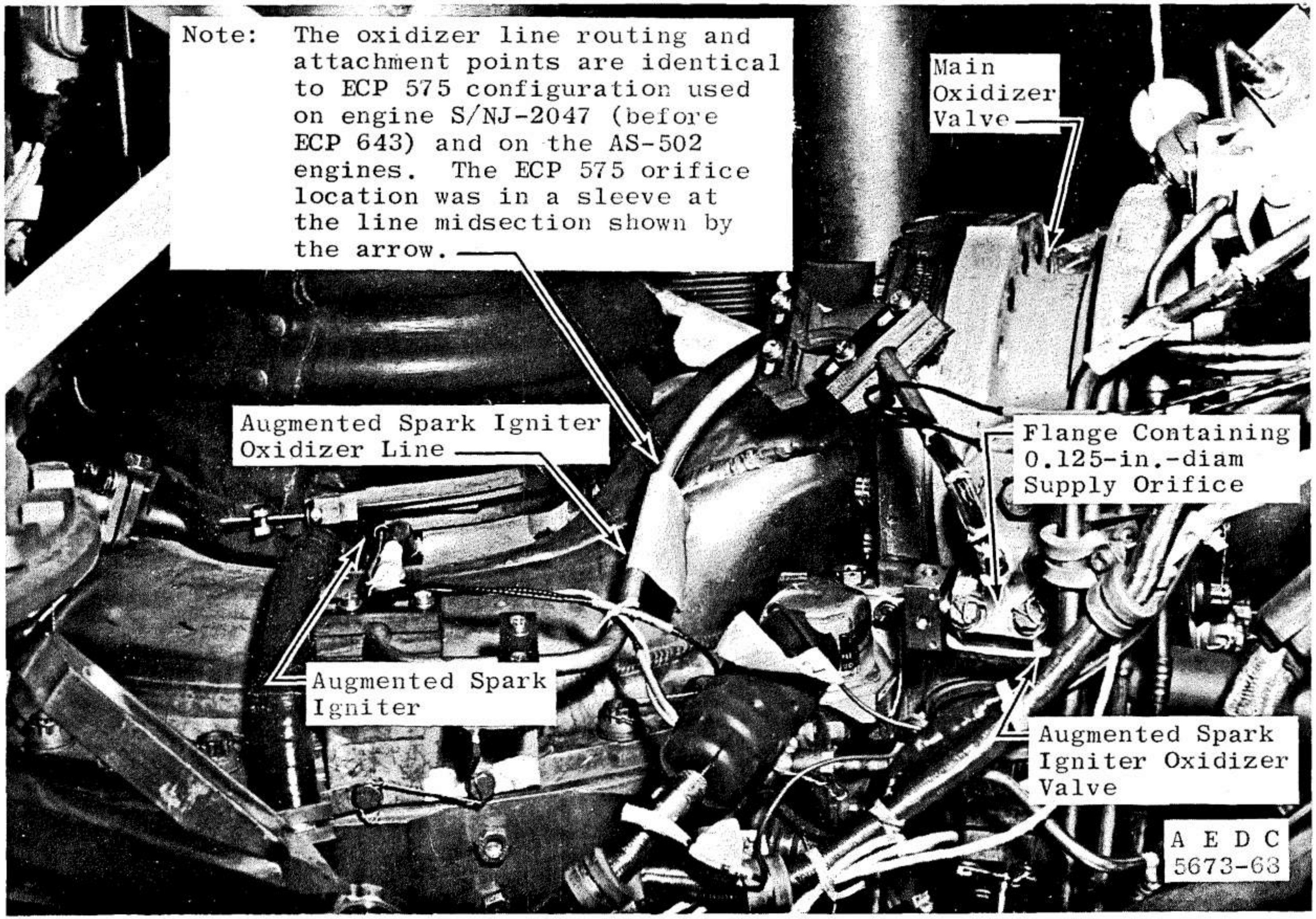
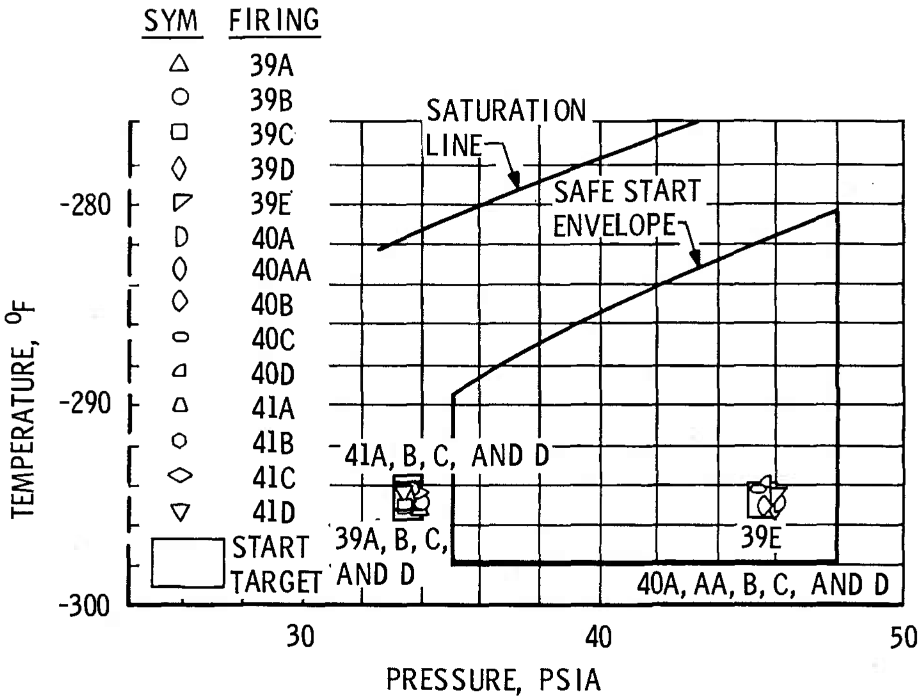
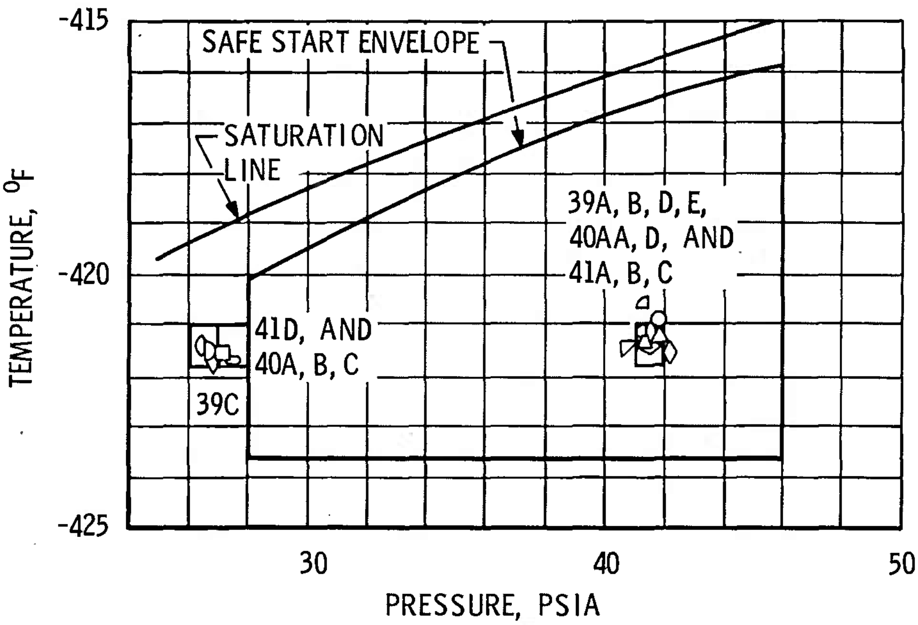


Fig. 9 Augmented Spark Igniter Oxidizer Supply Line Modifications

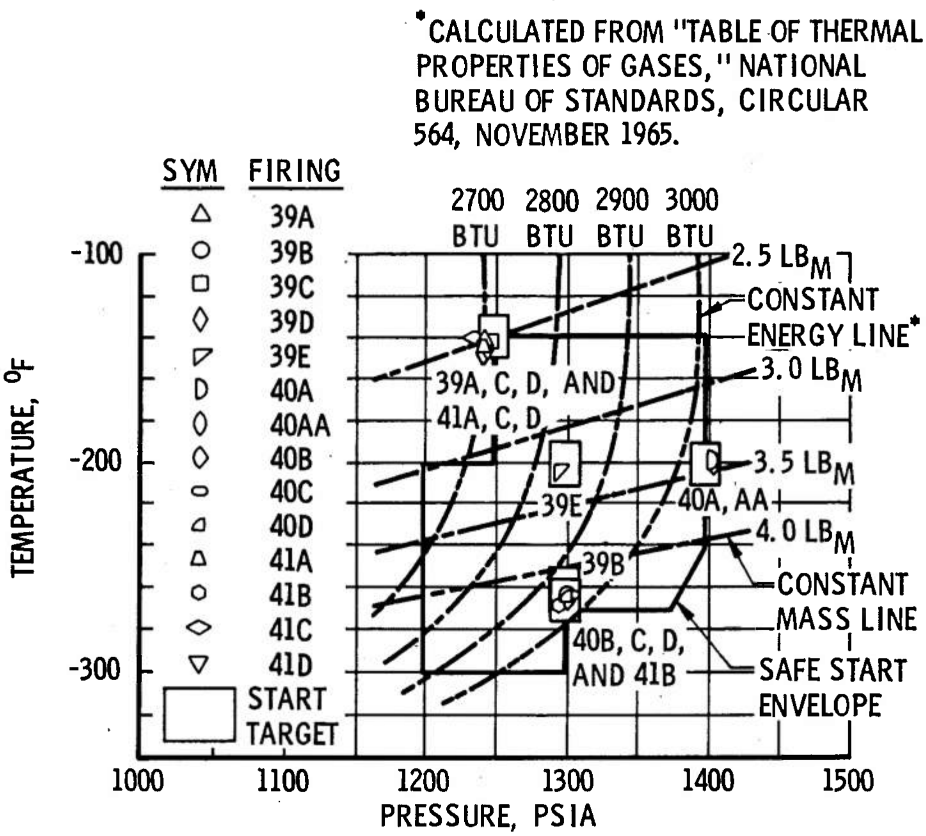


a. Oxidizer Pump Inlet

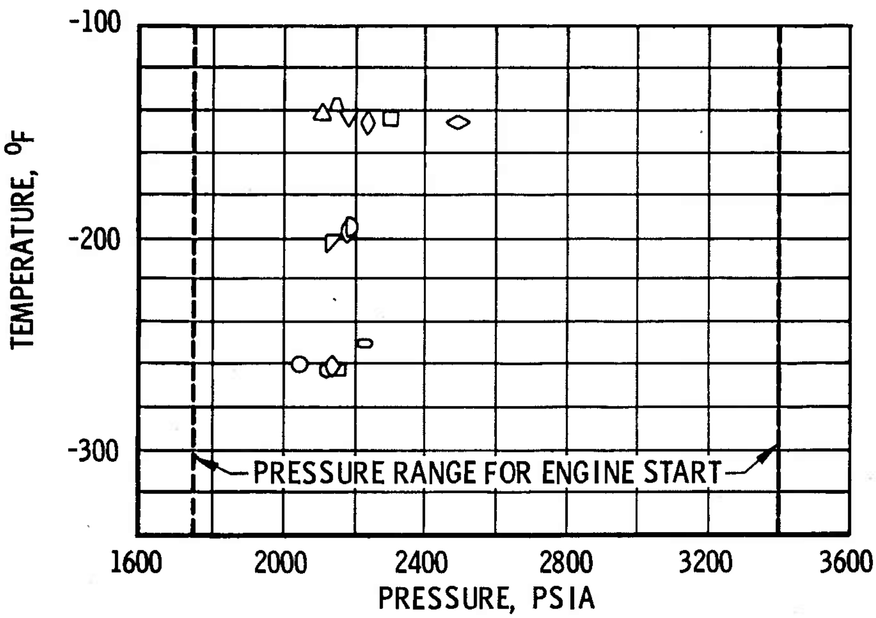


b. Fuel Pump Inlet

Fig. 10 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

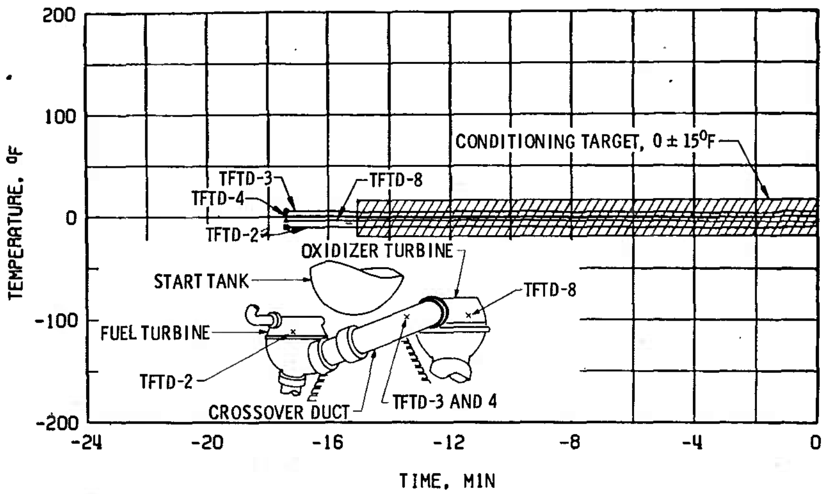


c. Start Tank

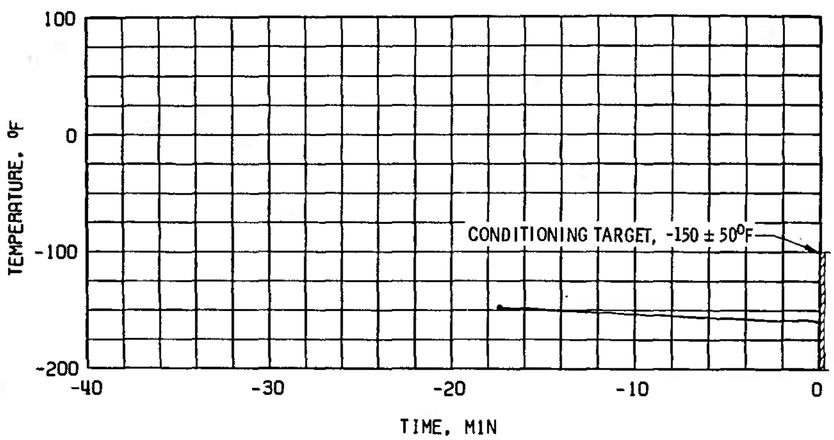


d. Helium Tank

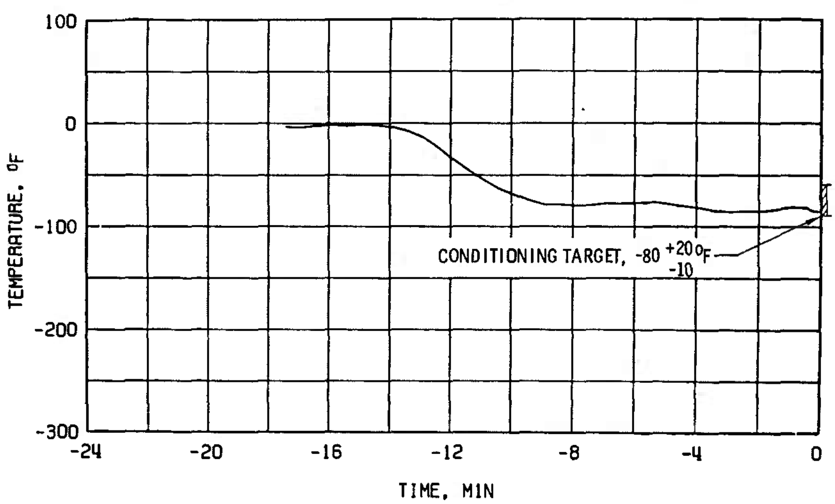
Fig. 10 Concluded



a. Crossover Duct, TFTD

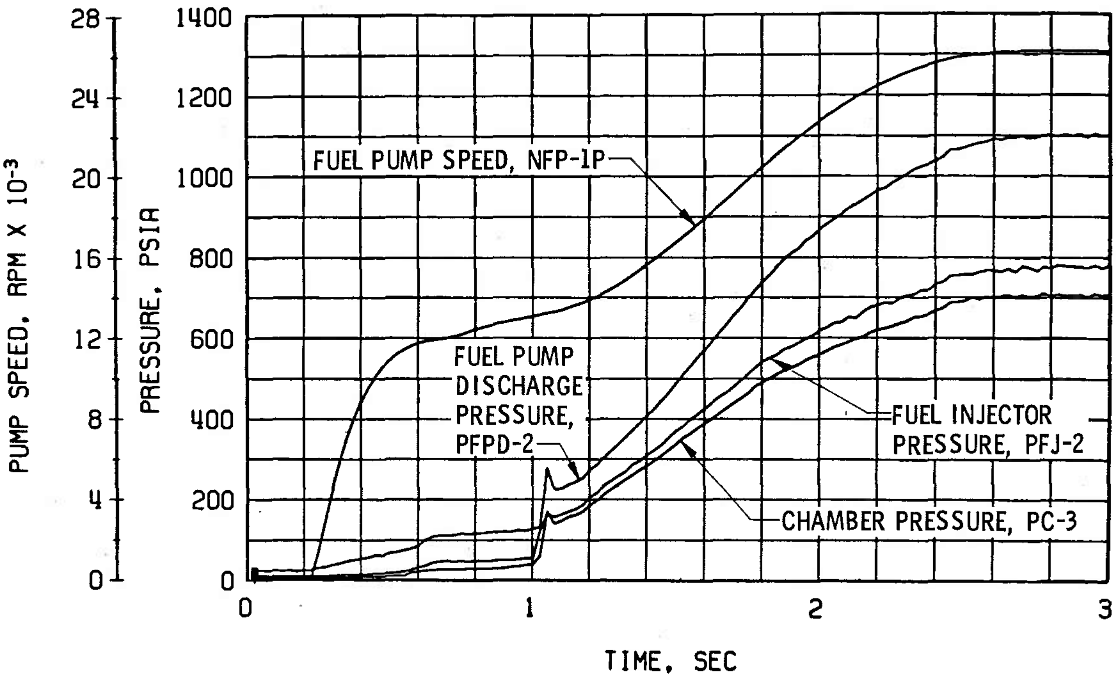


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

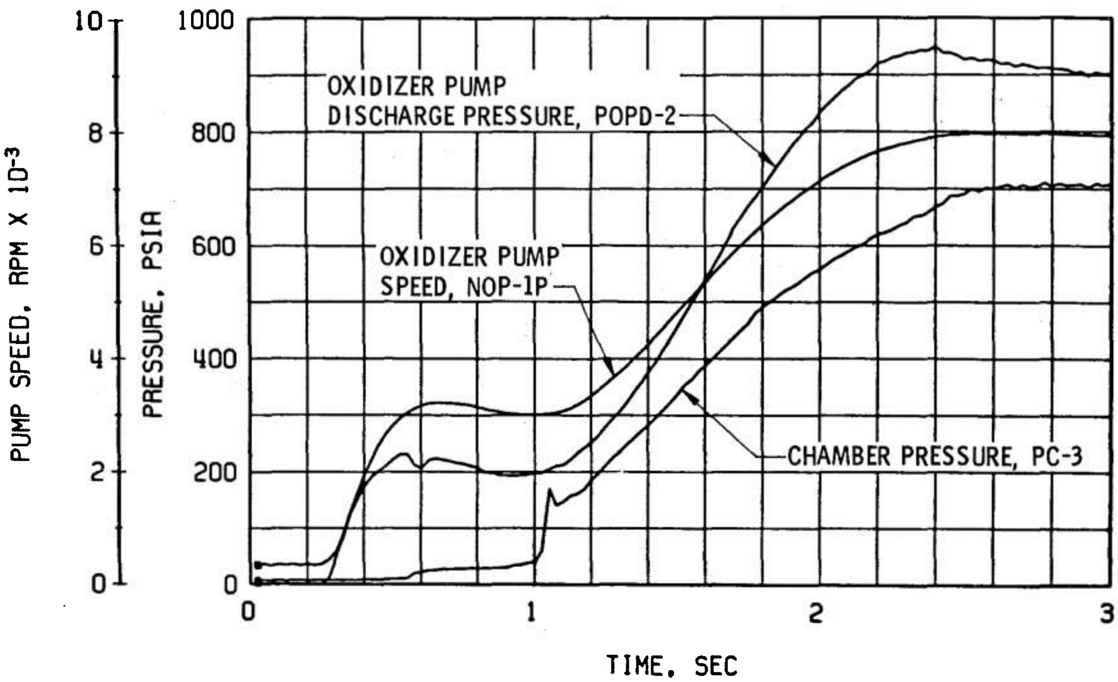


c. Thrust Chamber Throat, TTC-1P

Fig. 11 Thermal Conditioning History of Engine Components, Firing 39A

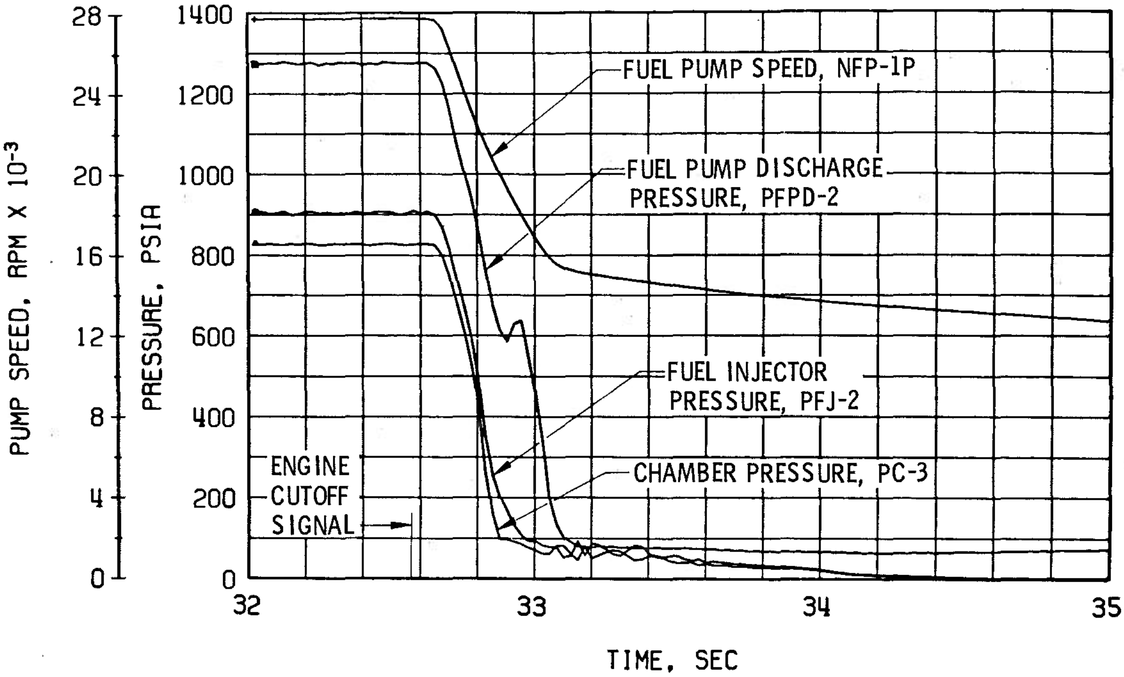


a. Thrust Chamber Fuel System, Start

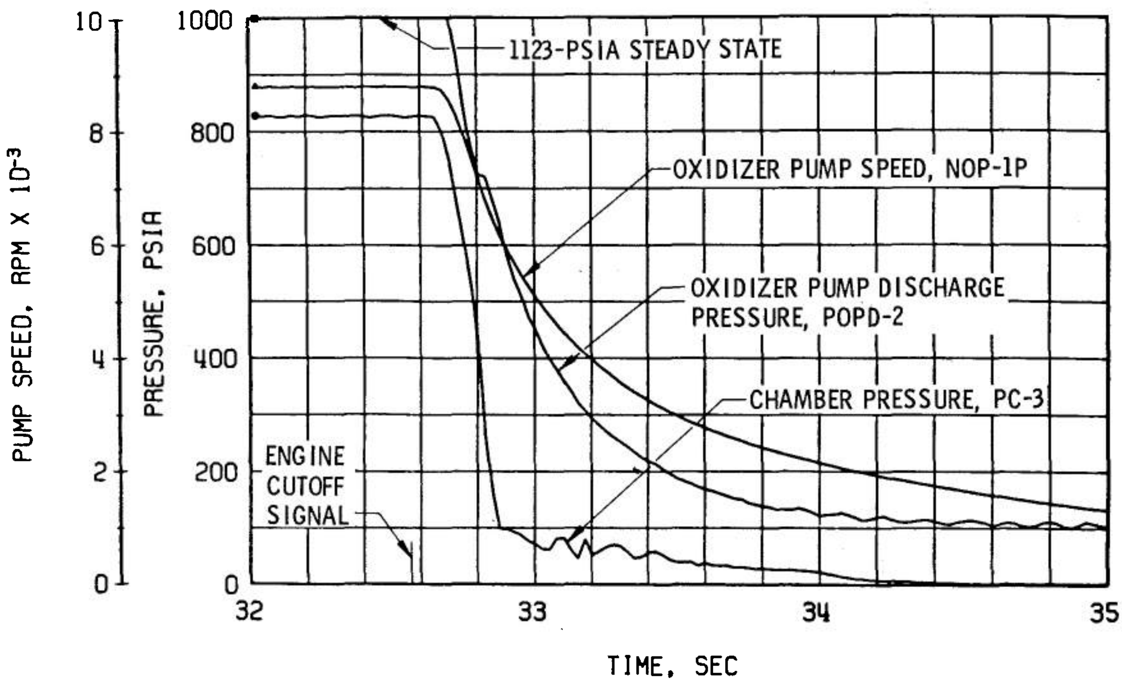


b. Thrust Chamber Oxidizer System, Start

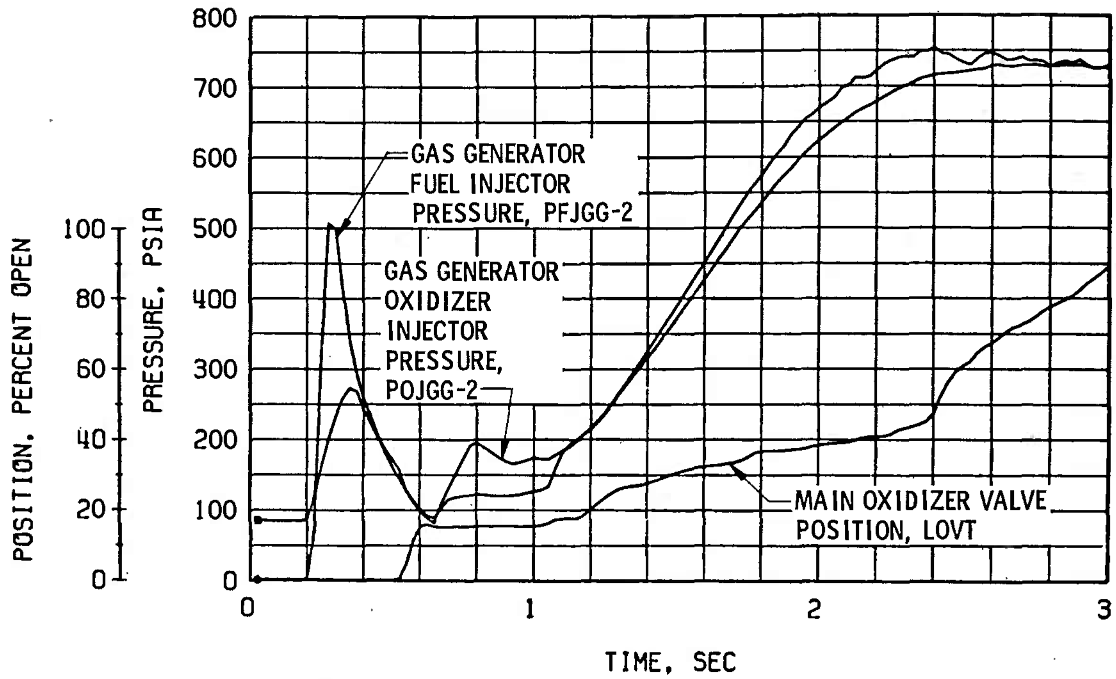
Fig. 12 Engine Transient Operation, Firing 39A



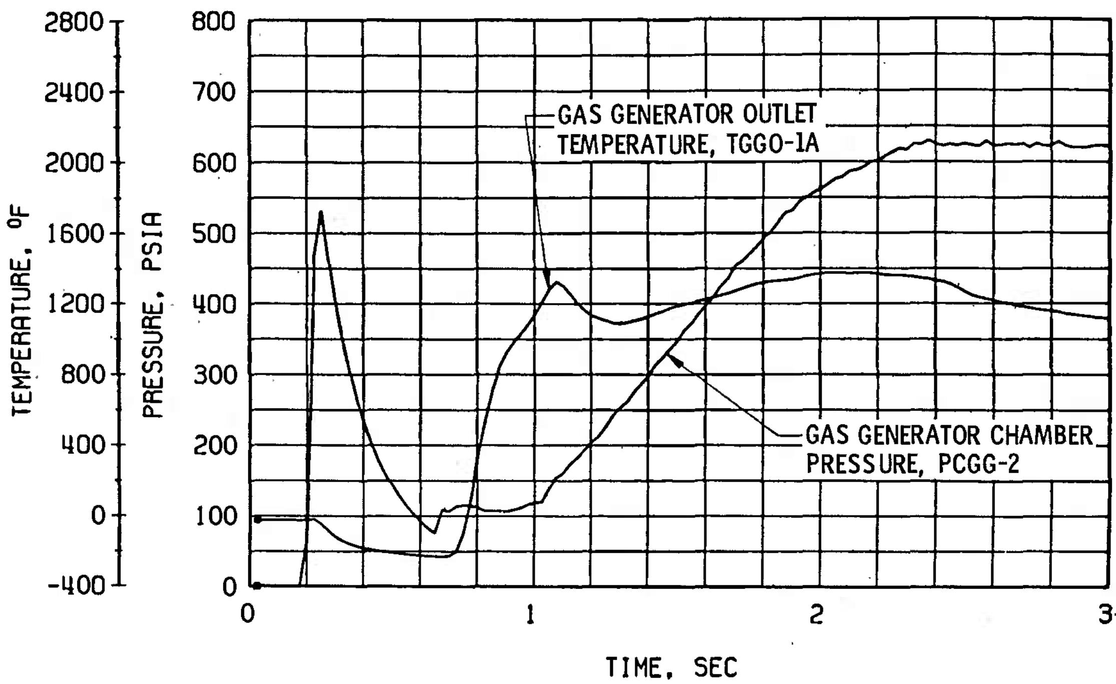
c. **Thrust Chamber Fuel System, Shutdown**



d. **Thrust Chamber Oxidizer System, Shutdown**
Fig. 12 Continued

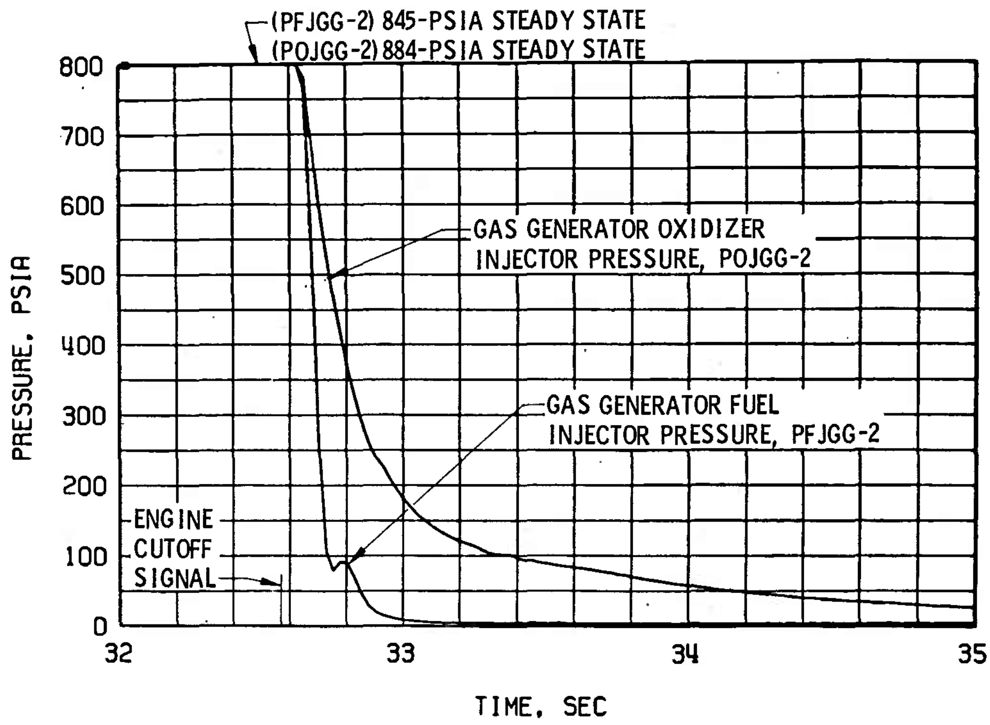


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

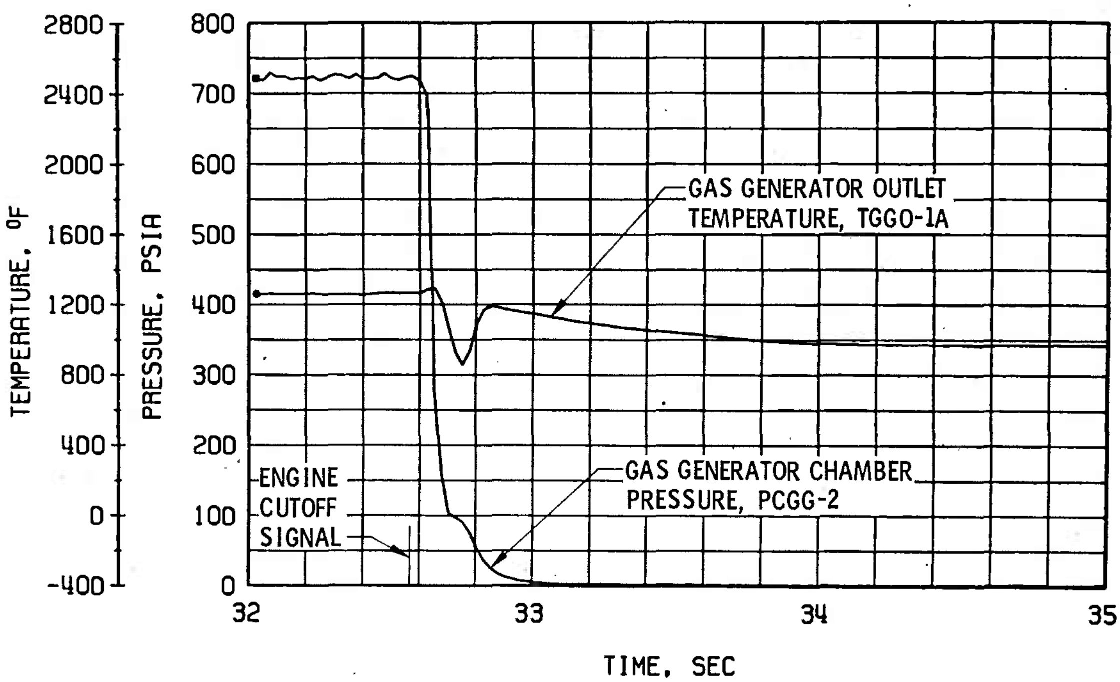


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 12 Continued

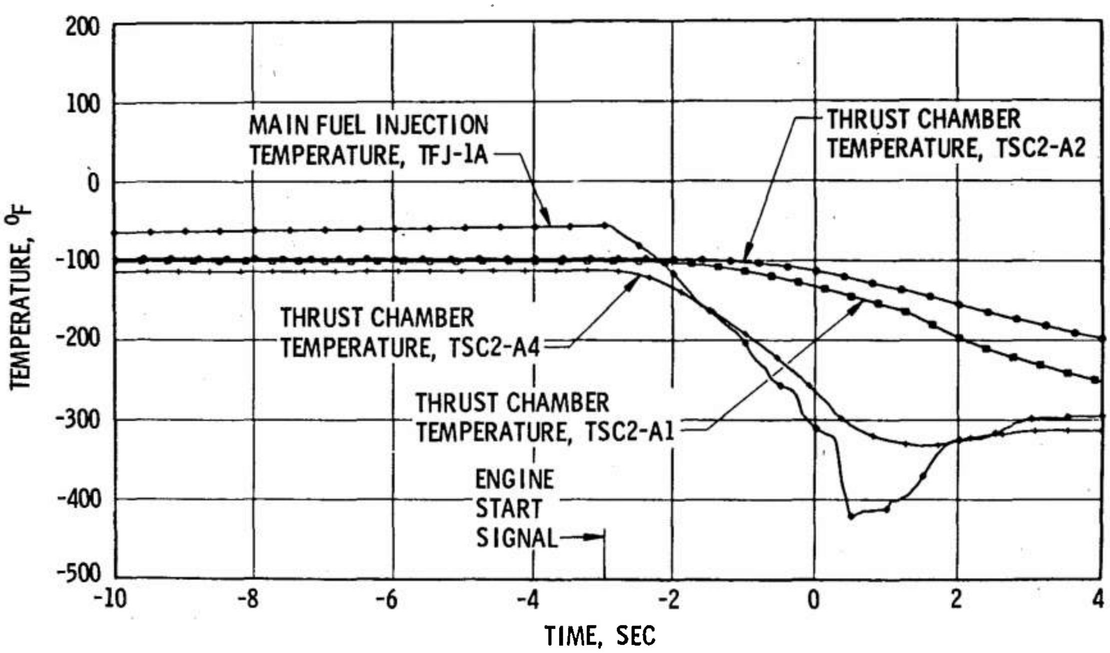


g. Gas Generator Injector Pressures, Shutdown

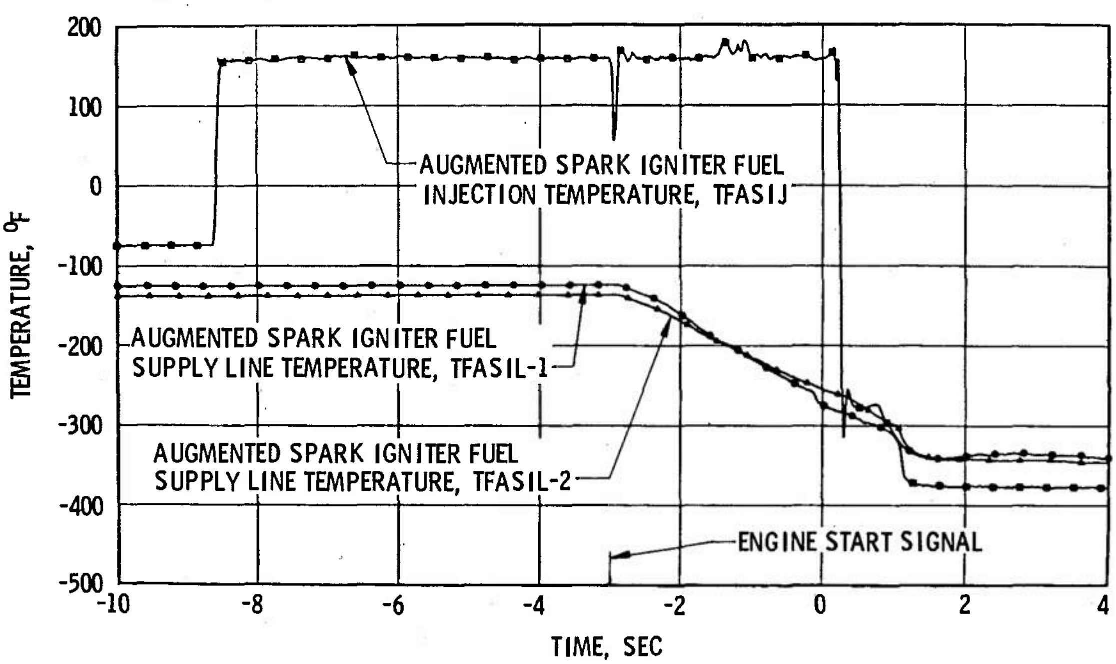


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 12 Continued

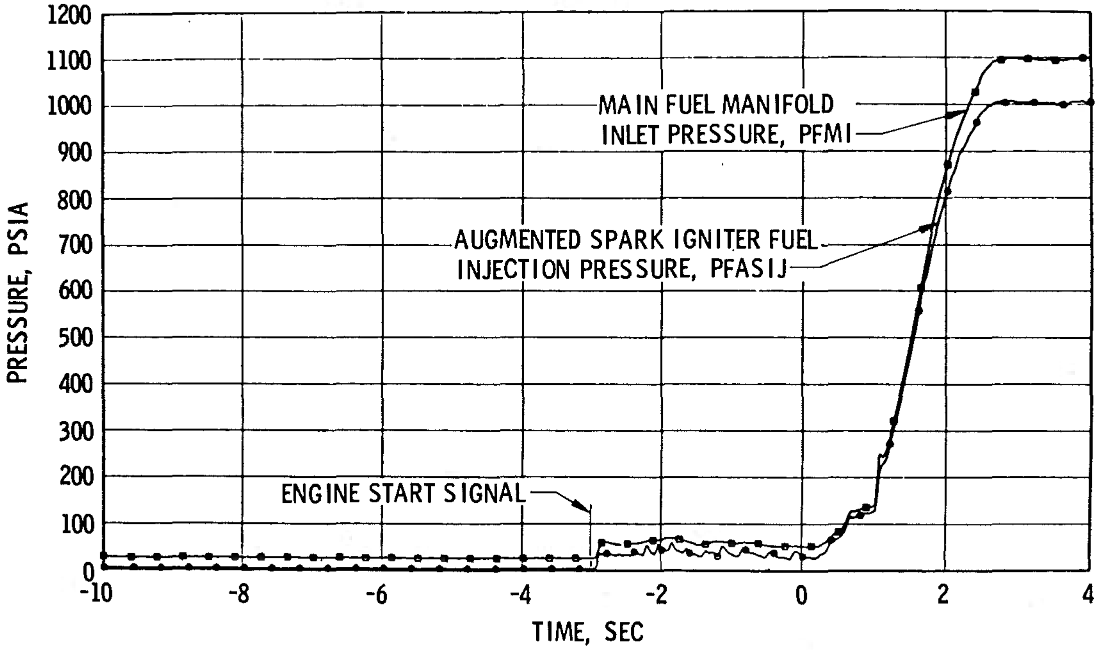


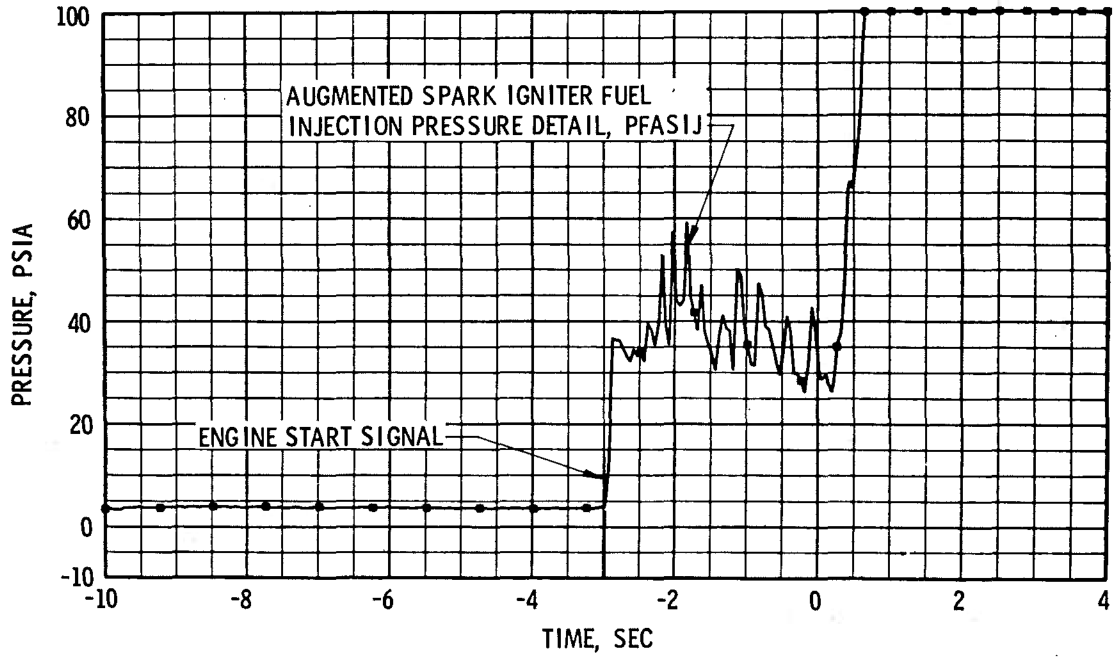
i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Temperature Transient, Start

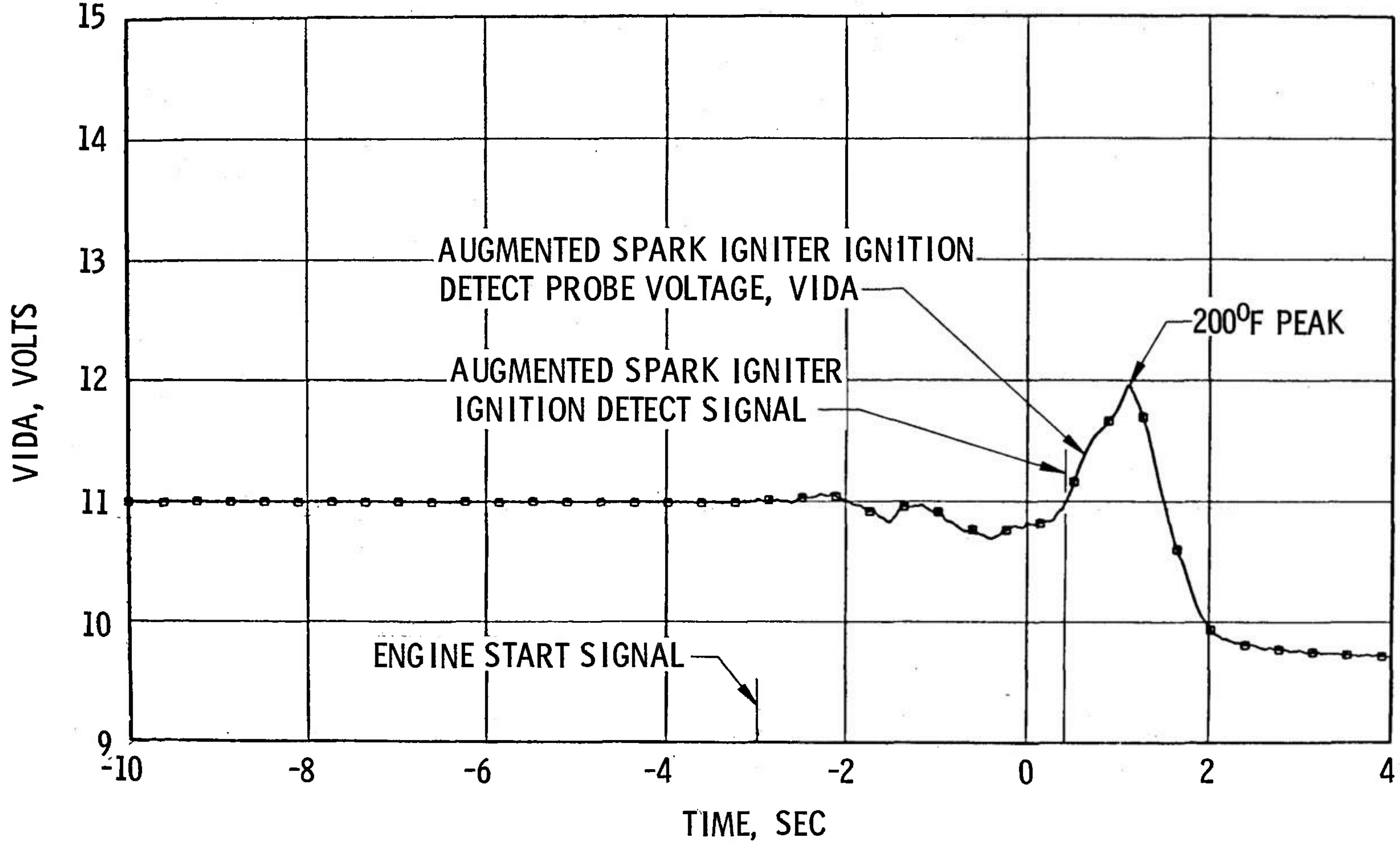
Fig. 12 Continued





k. Augmented Spark Igniter Fuel Supply Line Temperature Transient, Start

Fig. 12 Continued



l. Augmented Spork Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 12 Concluded

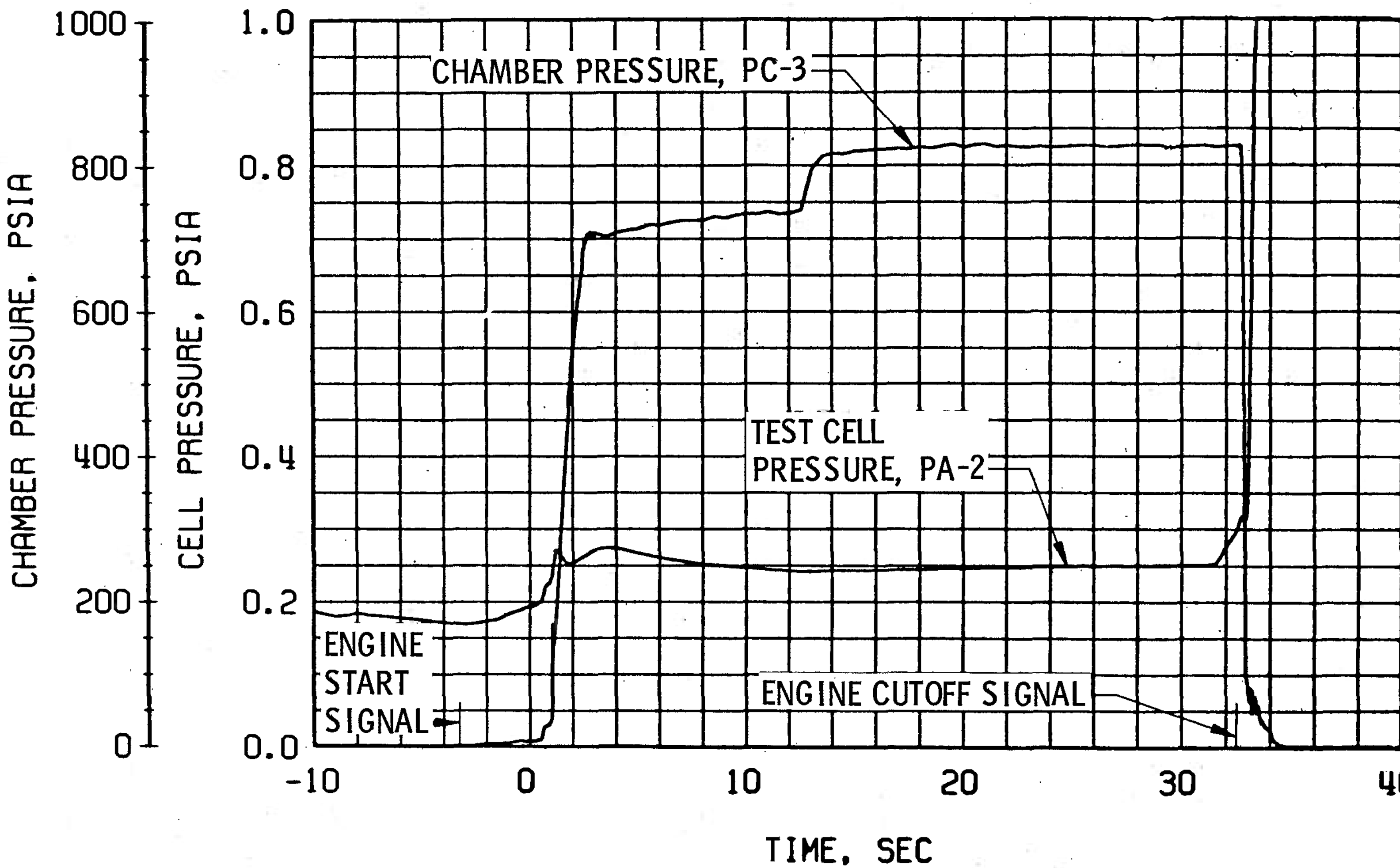


Fig. 13 Engine Ambient and Combustion Chamber Pressures, Firing 39A

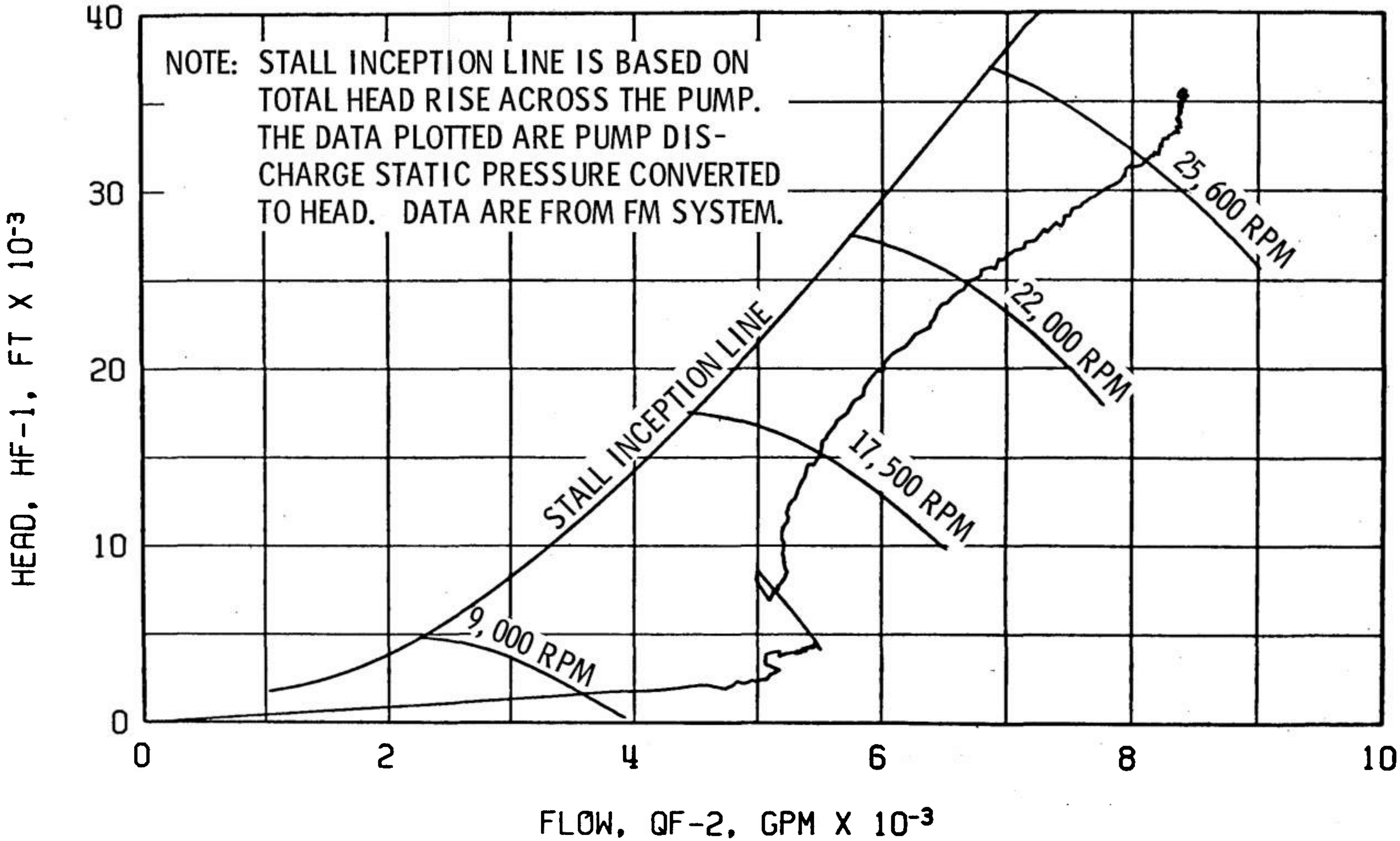
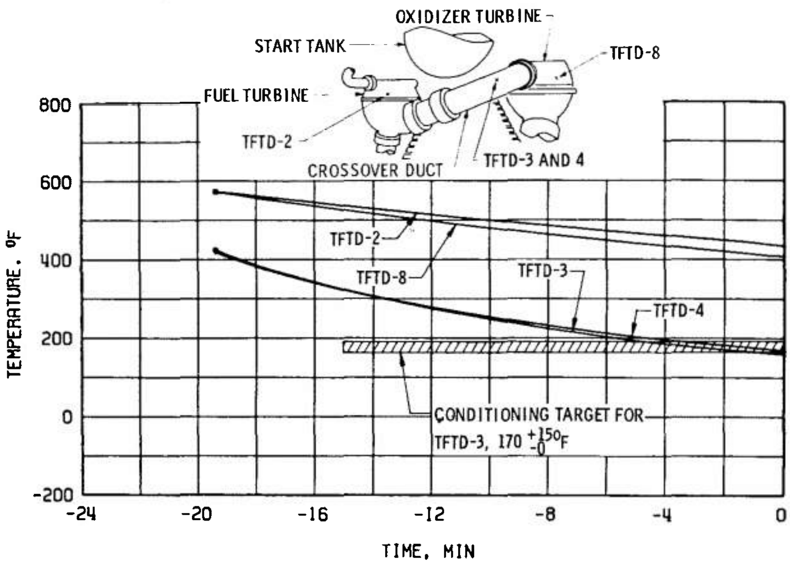
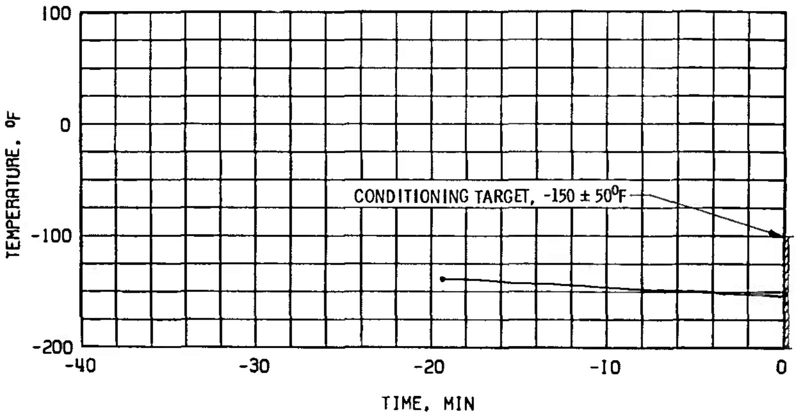


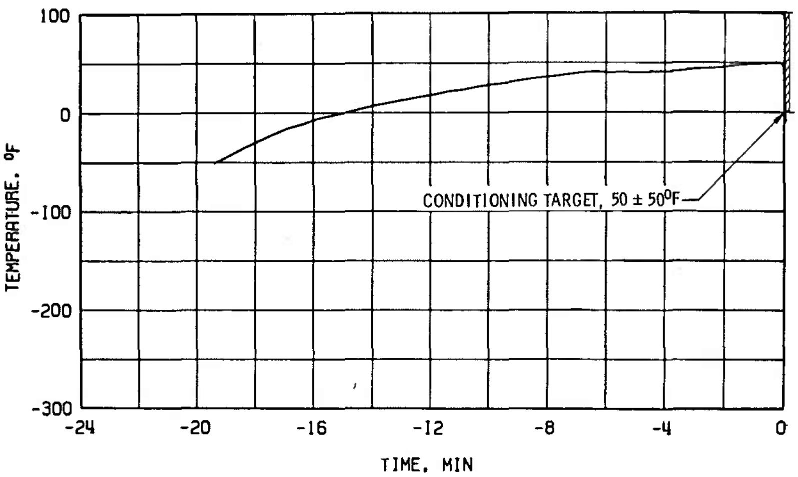
Fig. 14 Fuel Pump Start Transient Performance, Firing 39A



a. Crossover Duct, TFTD

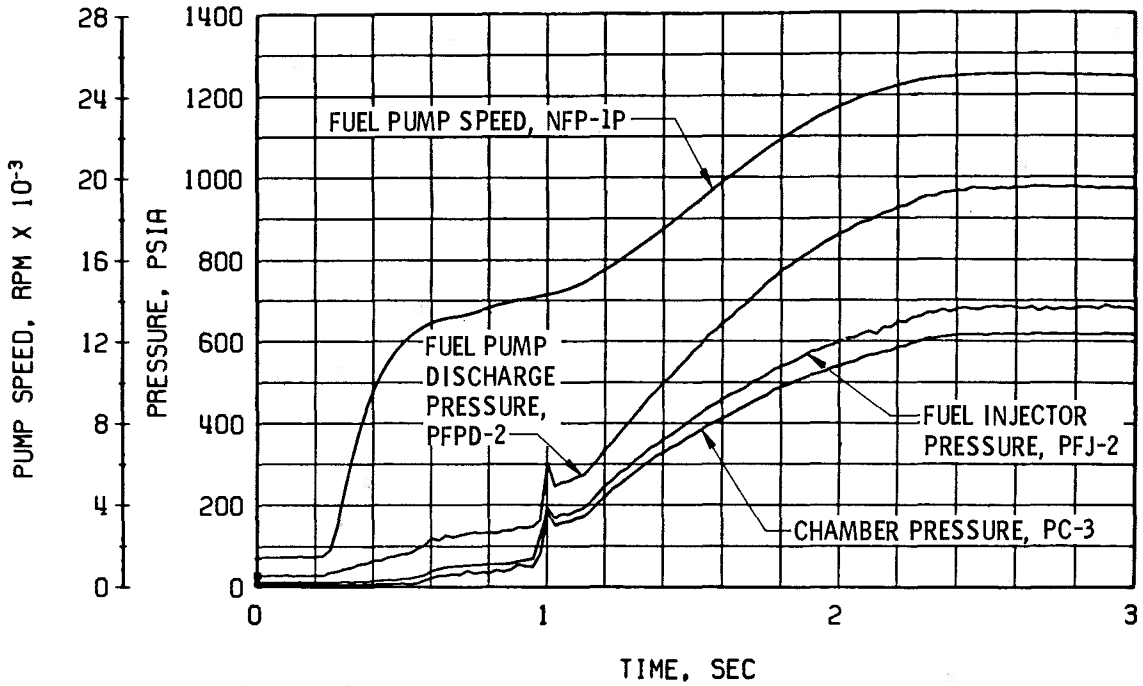


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

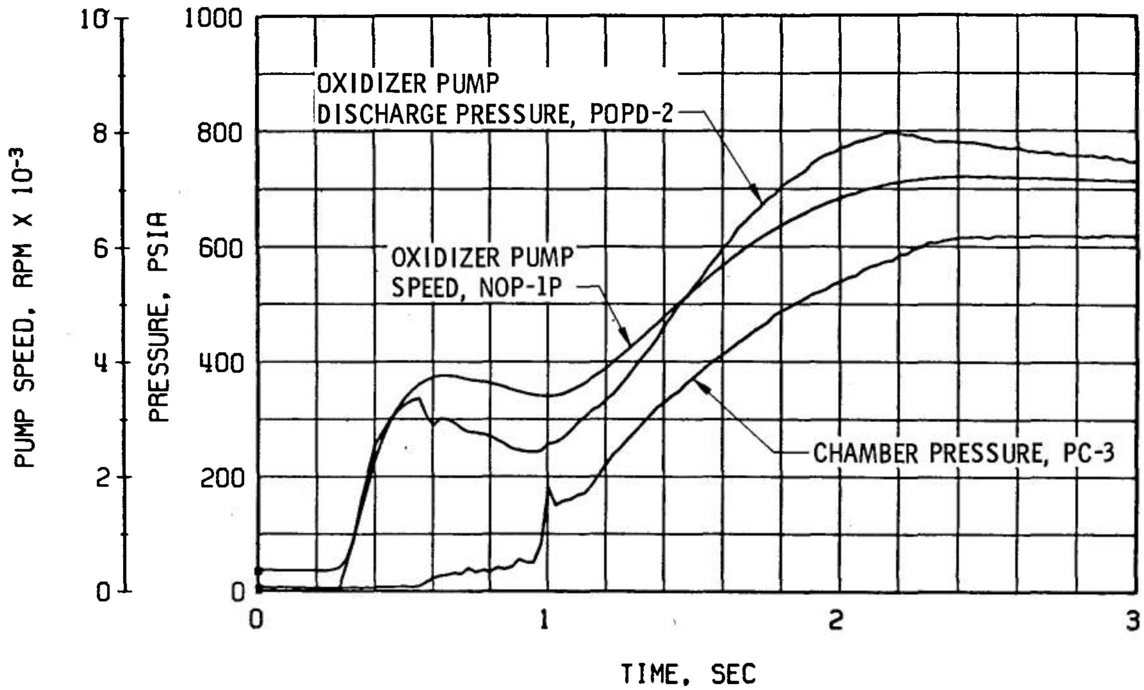


c. Thrust Chamber Throat, TTC-1P

Fig. 15 Thermal Conditioning History of Engine Components, Firing 39B

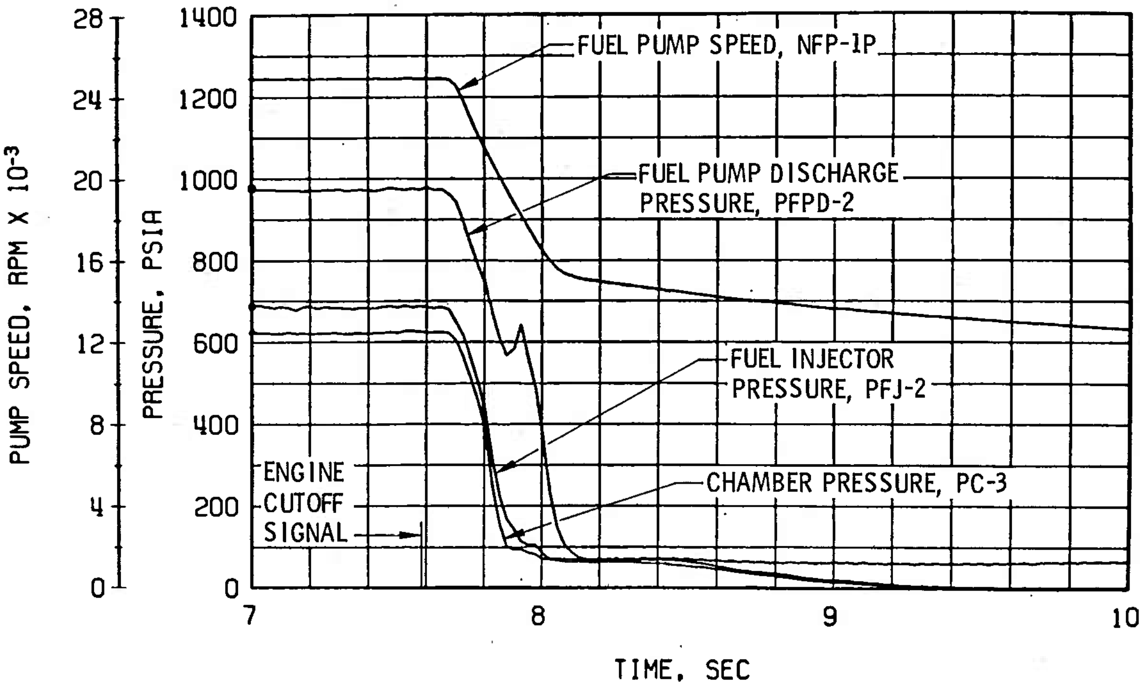


a. Thrust Chamber Fuel System, Start

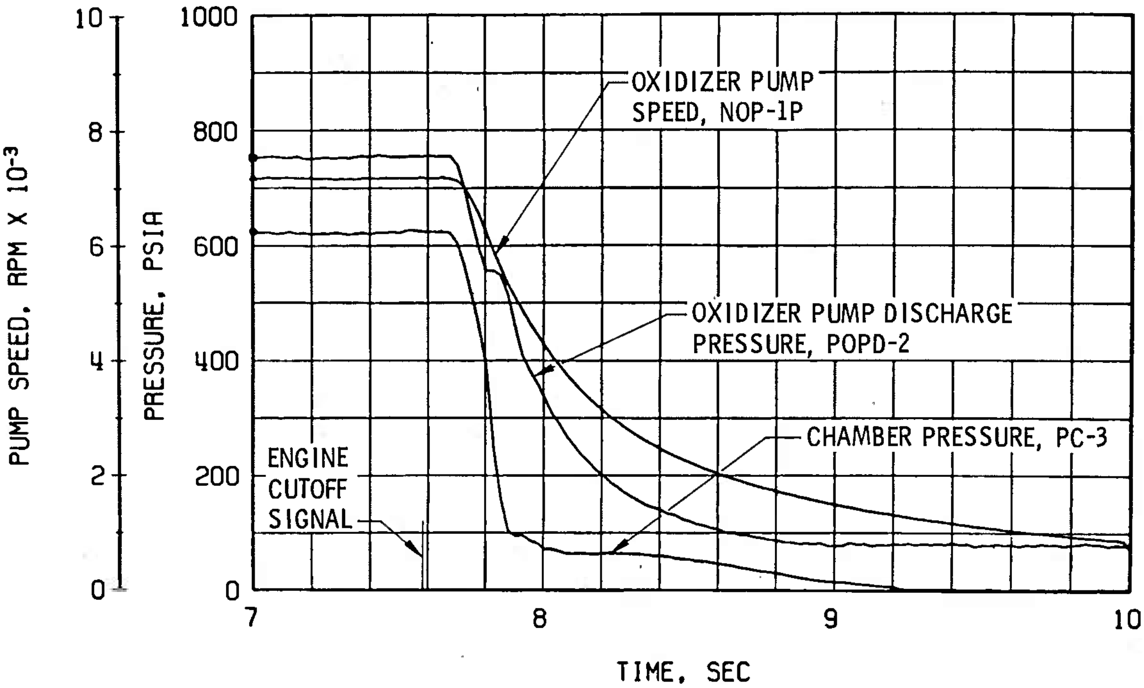


b. Thrust Chamber Oxidizer System, Start

Fig. 16 Engine Transient Performance, Firing 39B

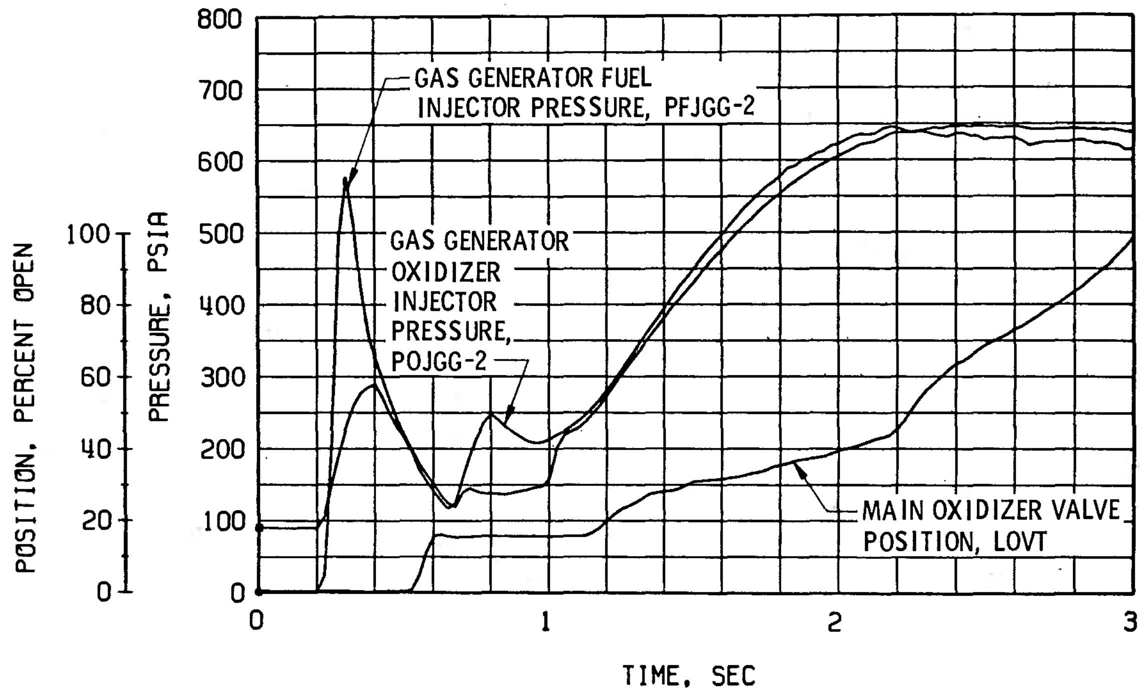


c. Thrust Chamber Fuel System, Shutdown

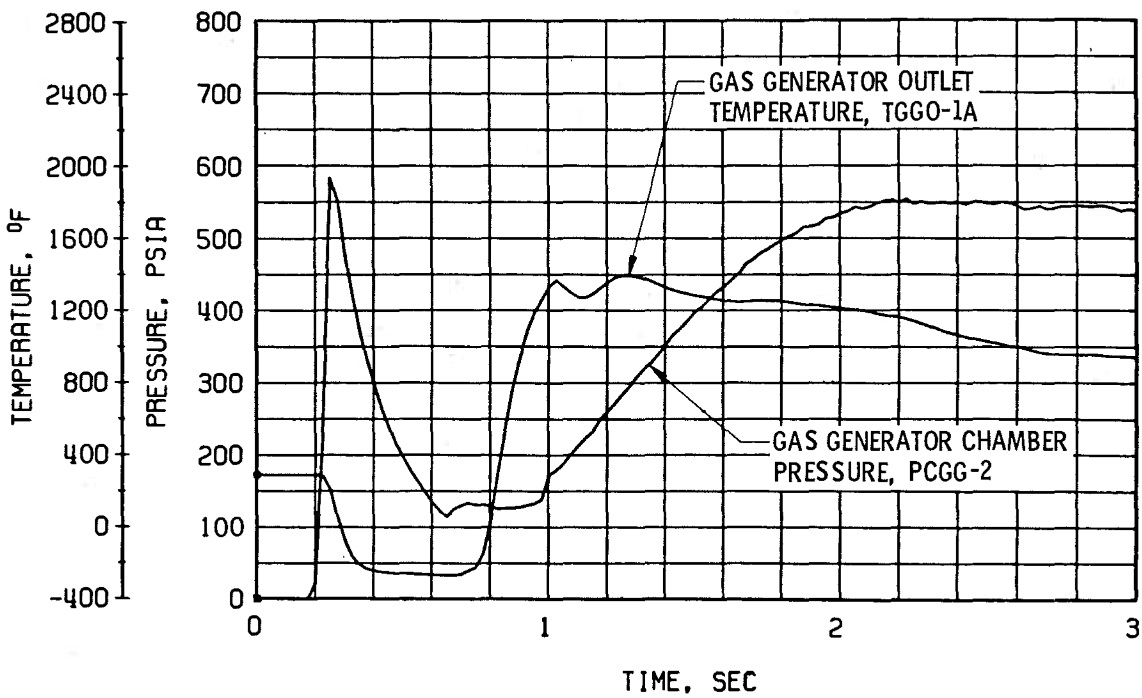


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 16 Continued

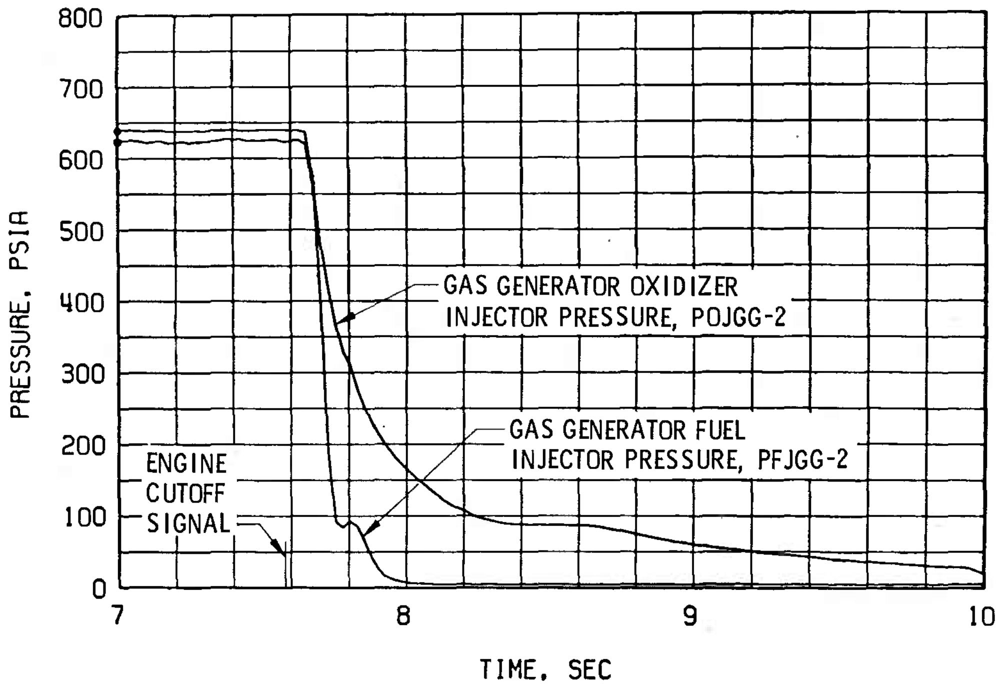


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

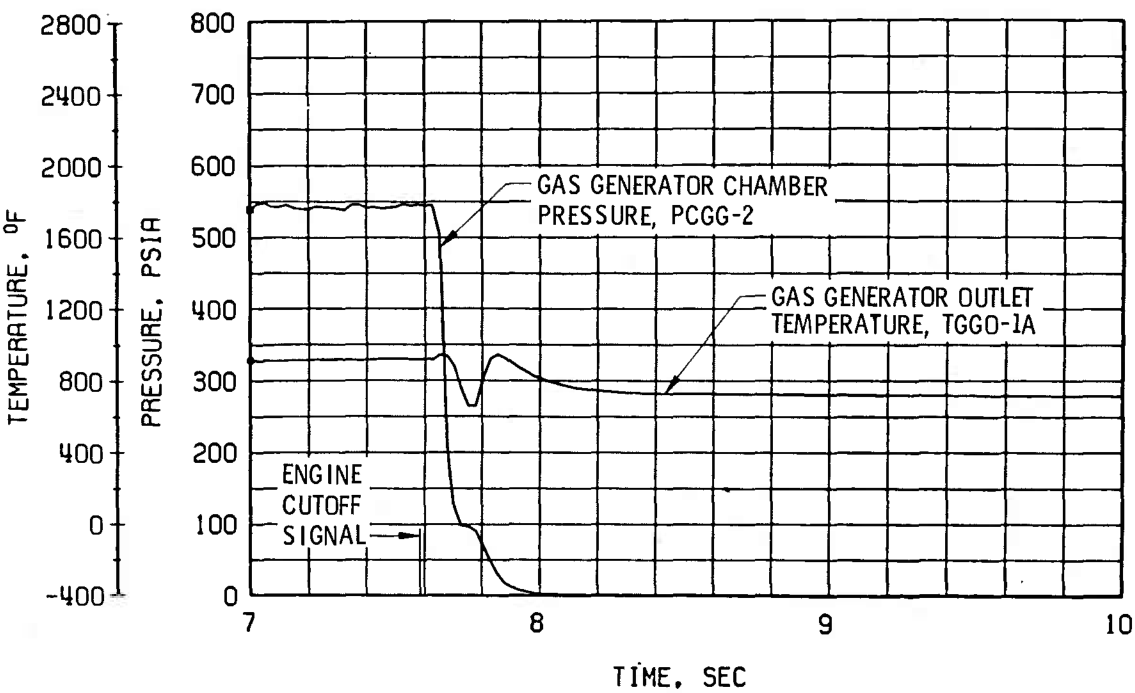


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 16 Continued

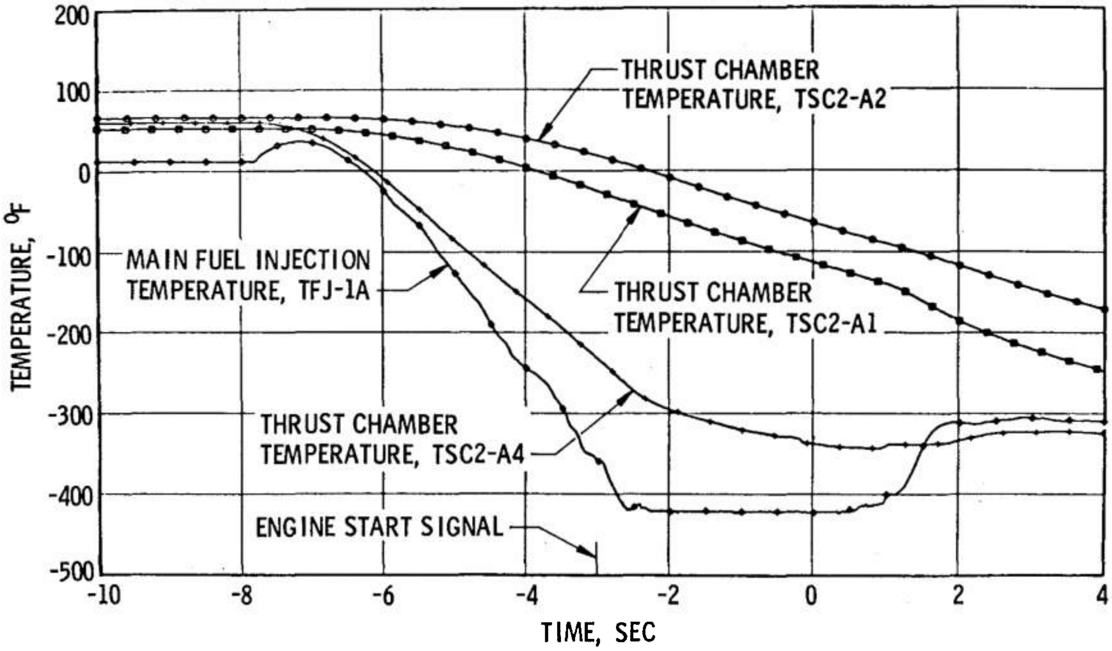


g. Gas Generator Injector Pressures, Shutdown

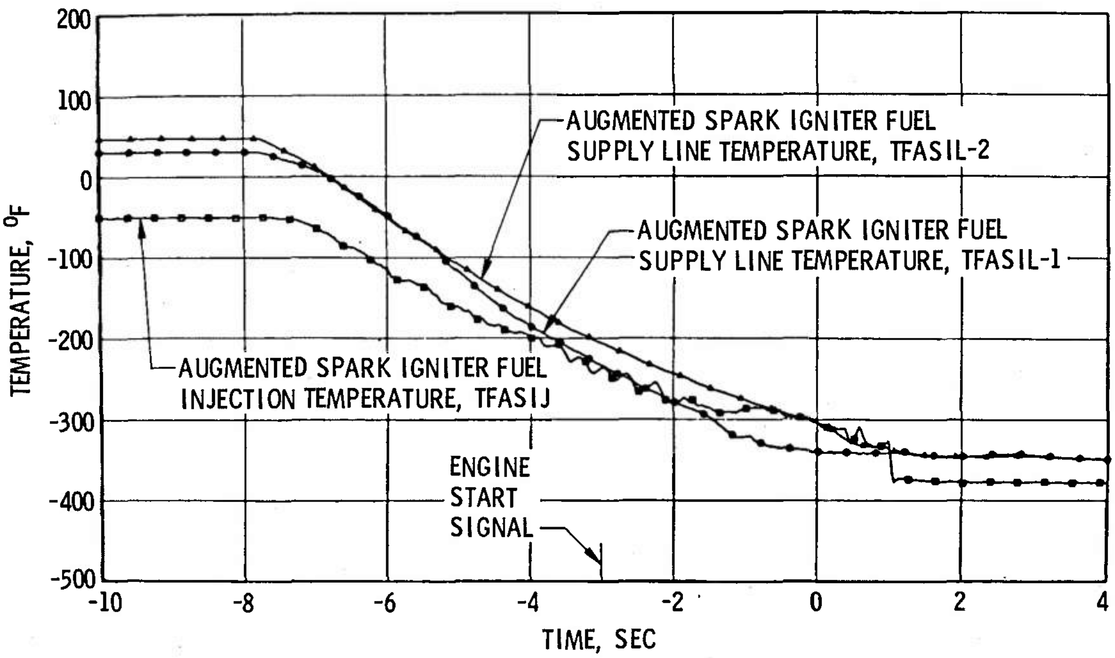


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 16 Continued

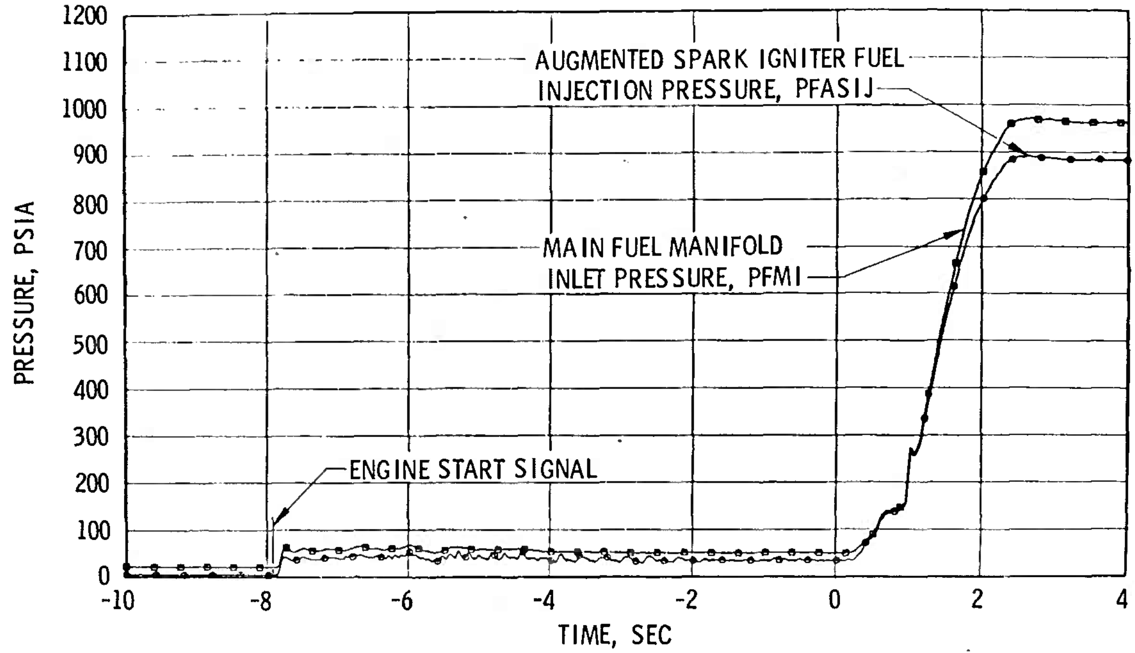


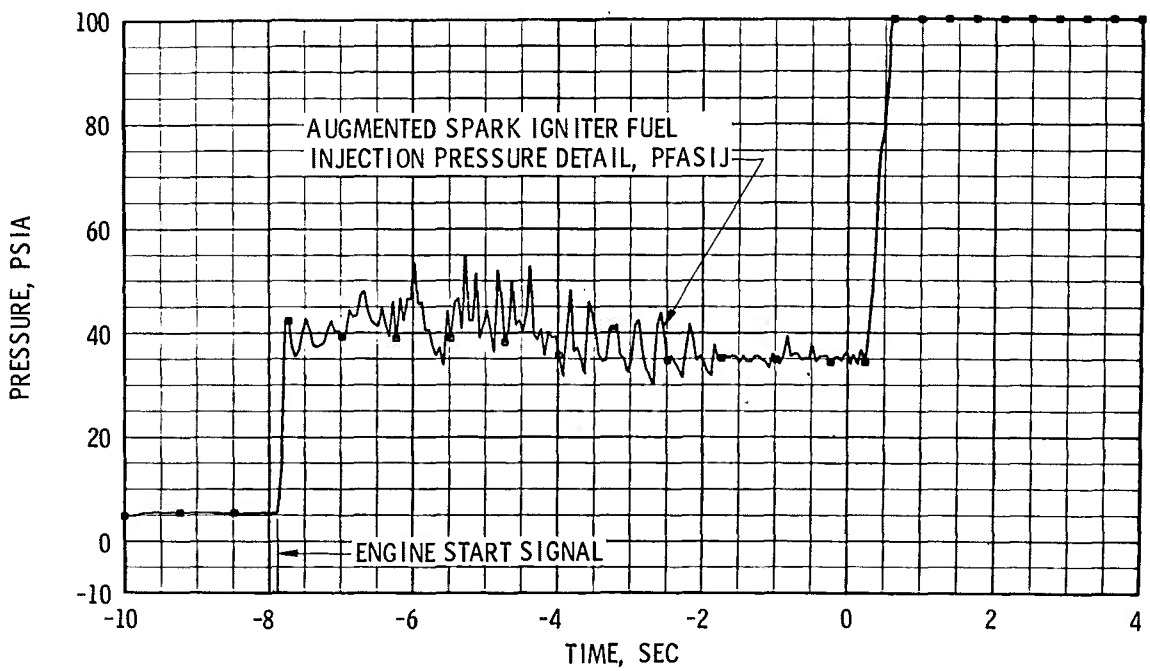
i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Temperature Transient, Start

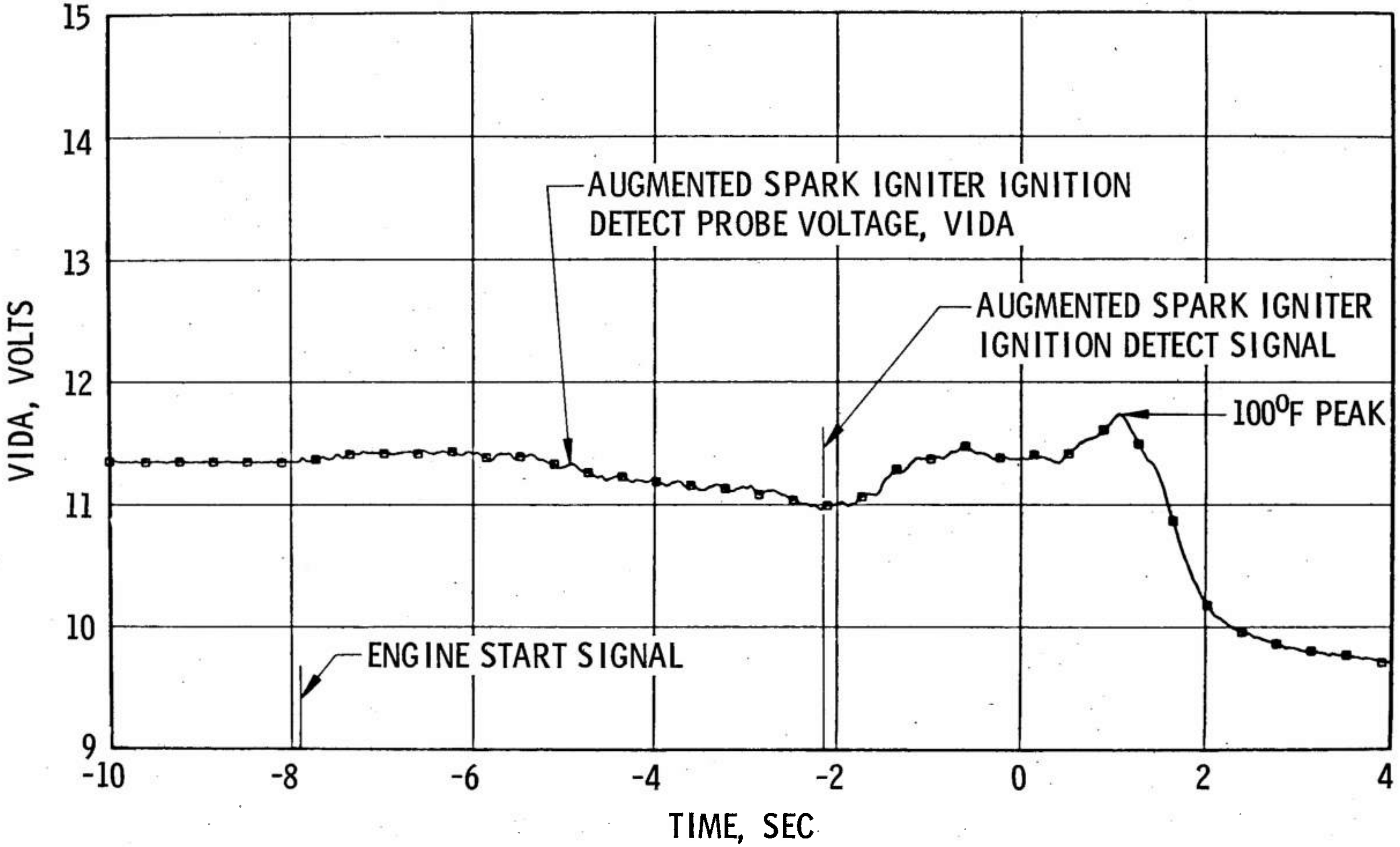
Fig. 16 Continued





k. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

Fig. 16 Continued



I. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 16 Concluded

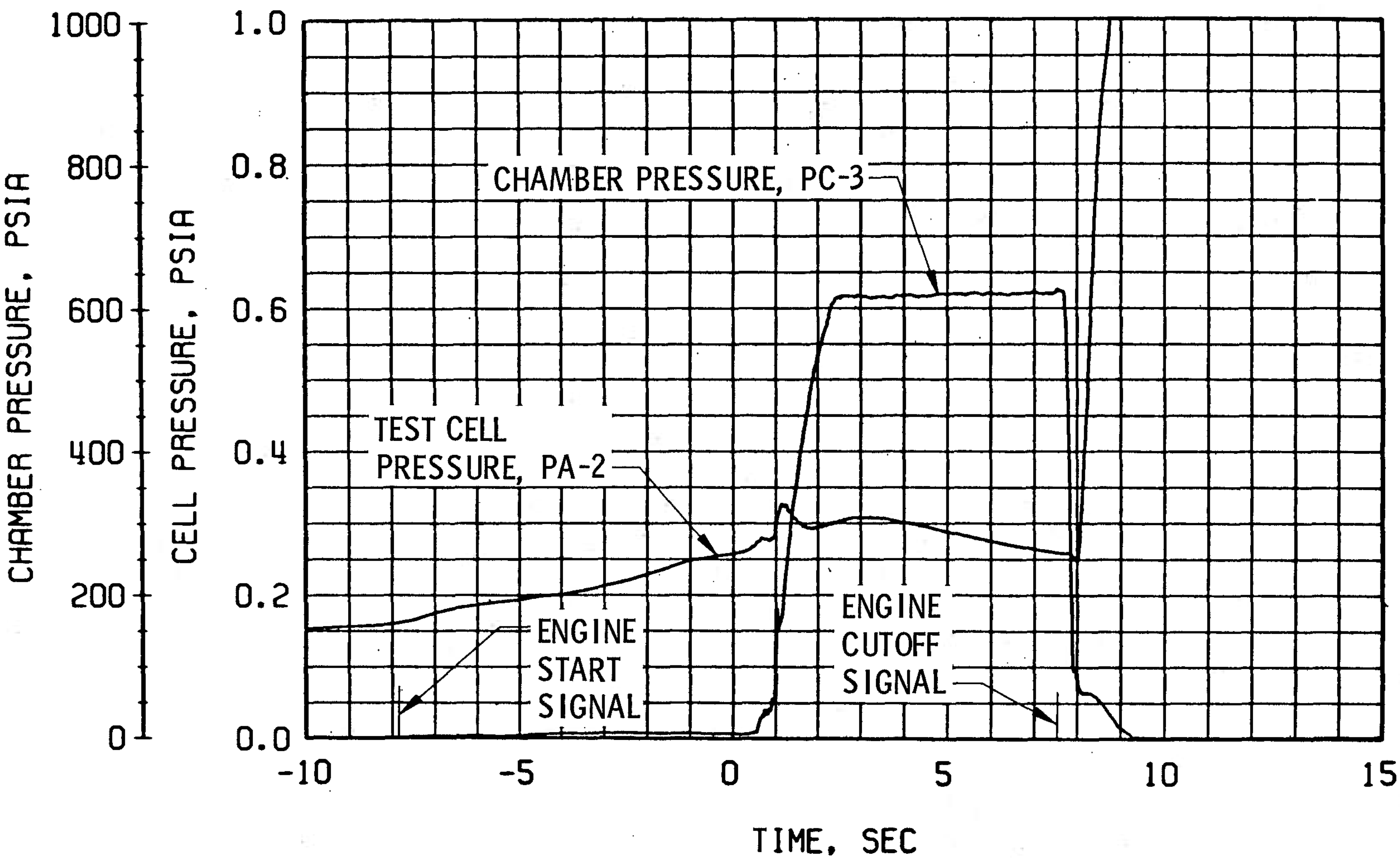


Fig. 17 Engine Ambient and Combustion Chamber Pressures, Firing 39B

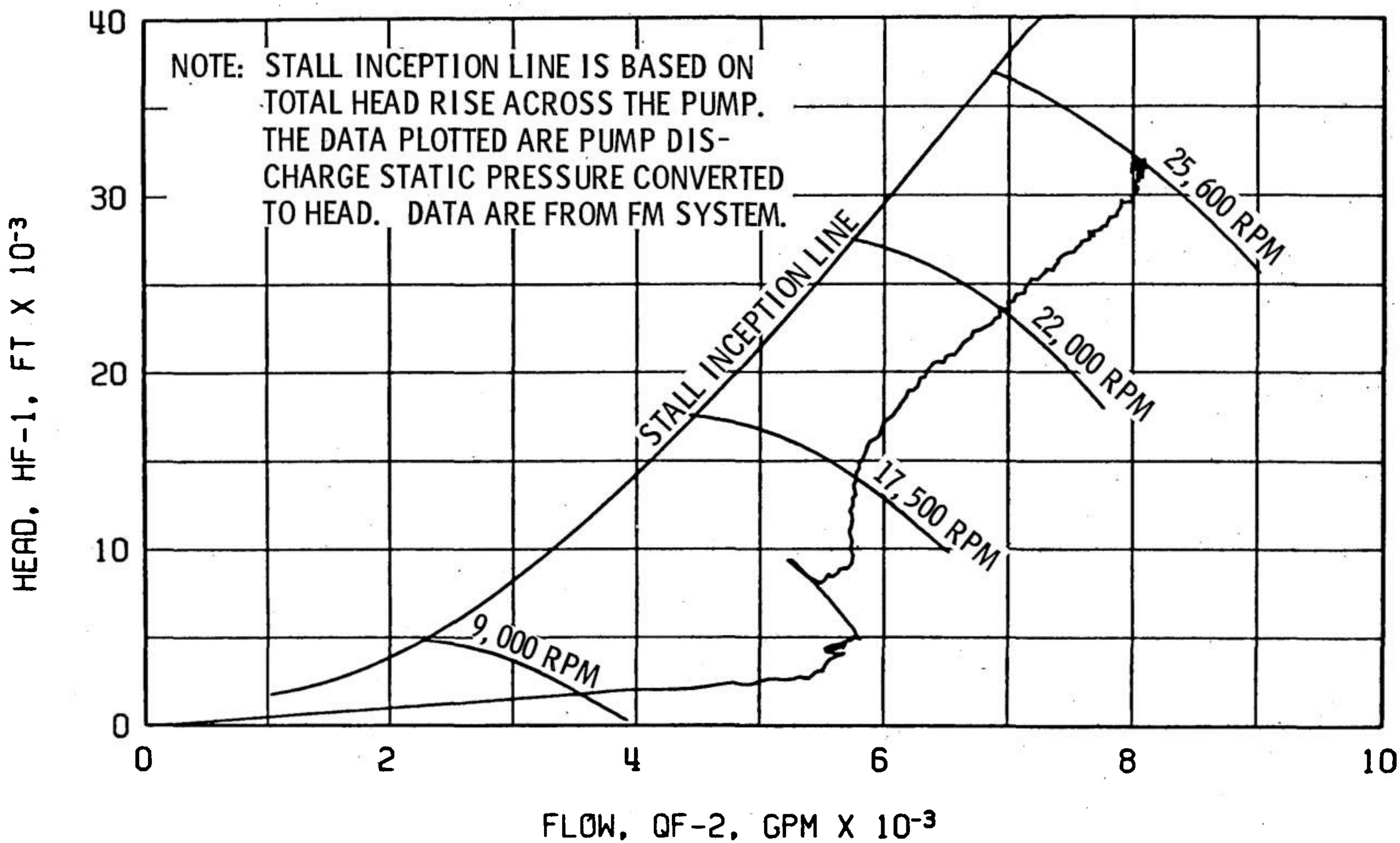
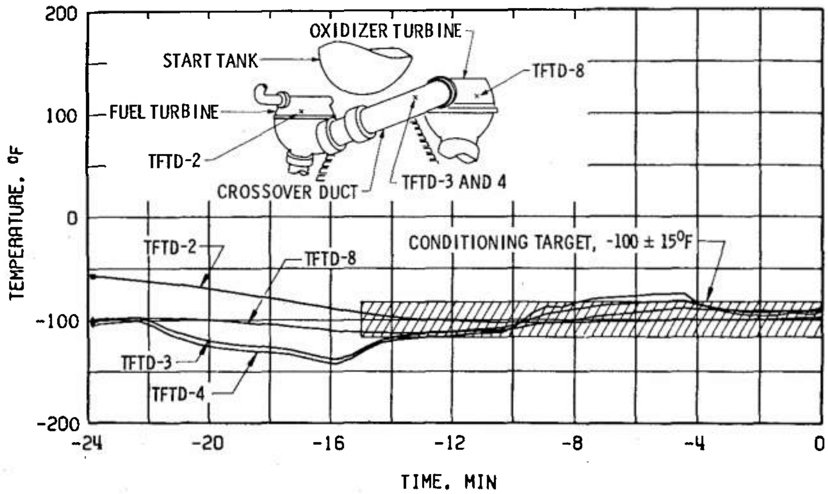
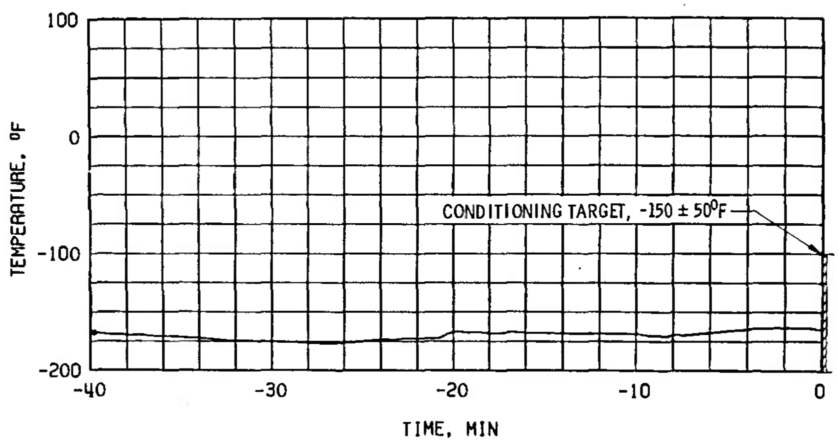


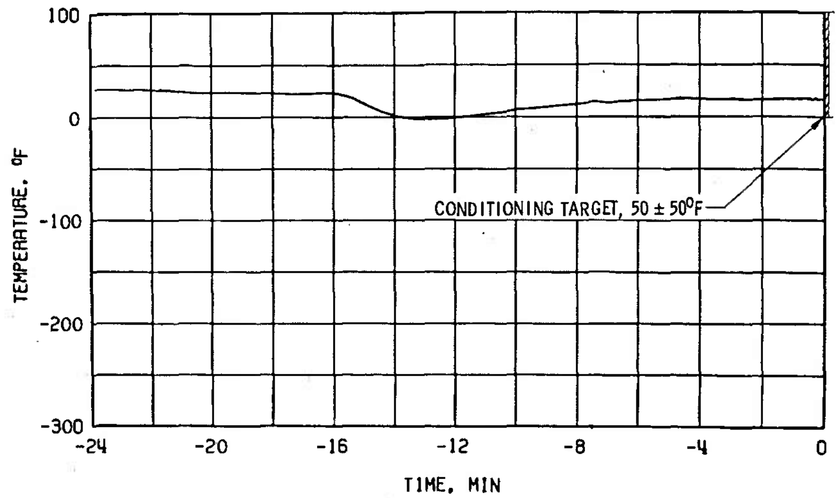
Fig. 18 Fuel Pump Start Transient Performance, Firing 39B



a. Crossover Duct, TFTD

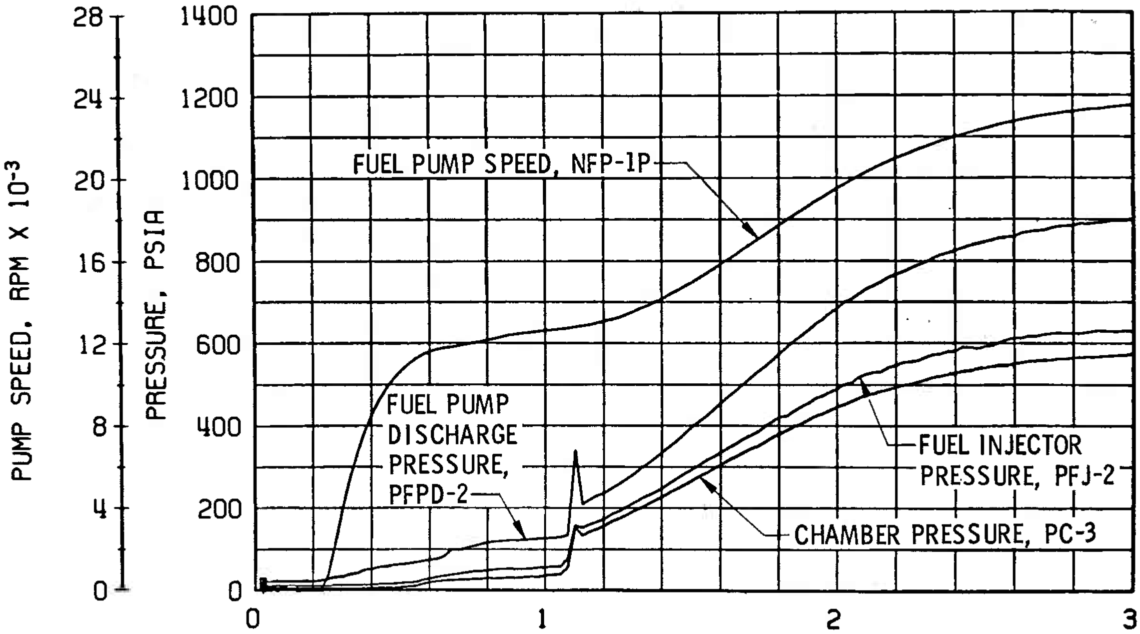


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

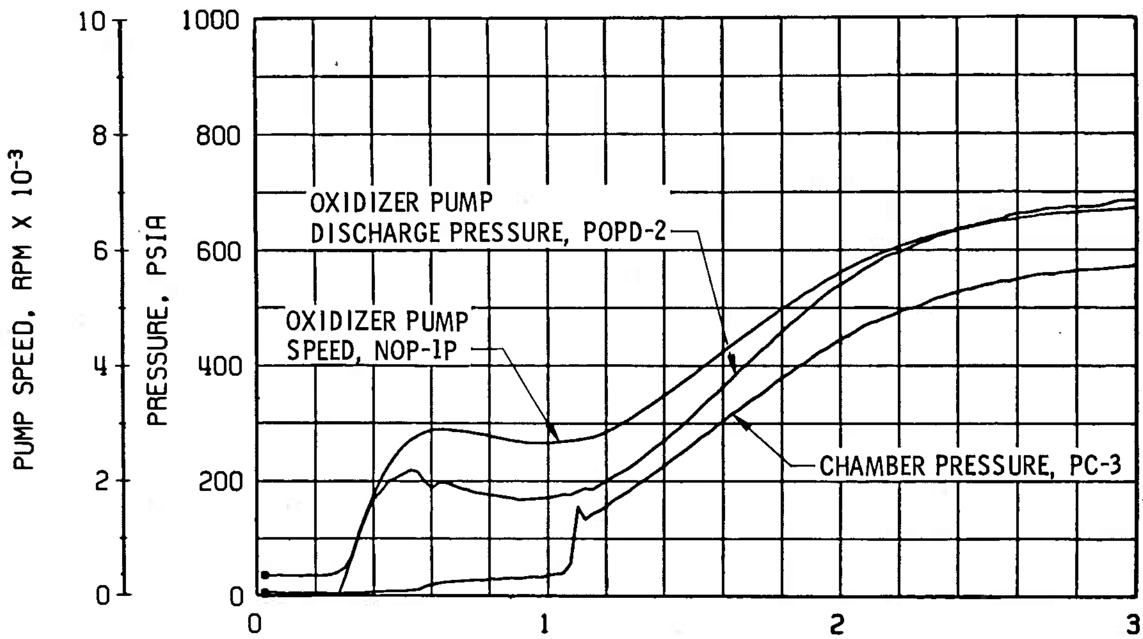


c. Thrust Chamber Throat, TTC-1P

Fig. 19 Thermal Conditioning History of Engine Components, Firing 39C

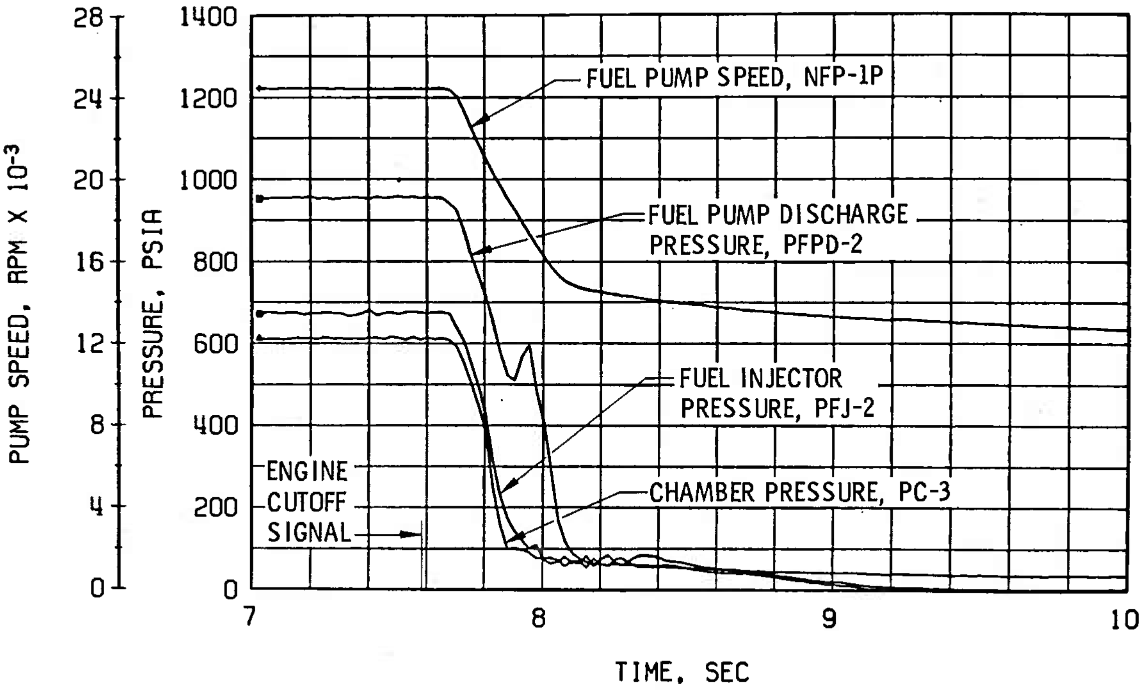


a. Thrust Chamber Fuel System, Start

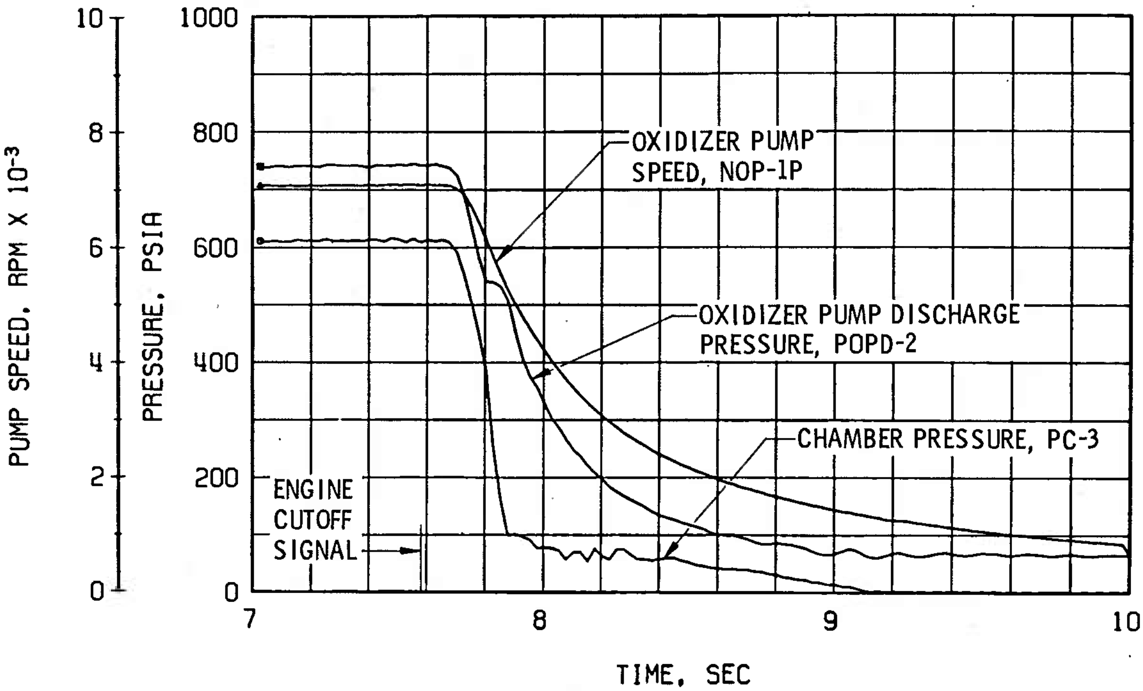


b. Thrust Chamber Oxidizer System, Start

Fig. 20 Engine Transient Operation, Firing 39C

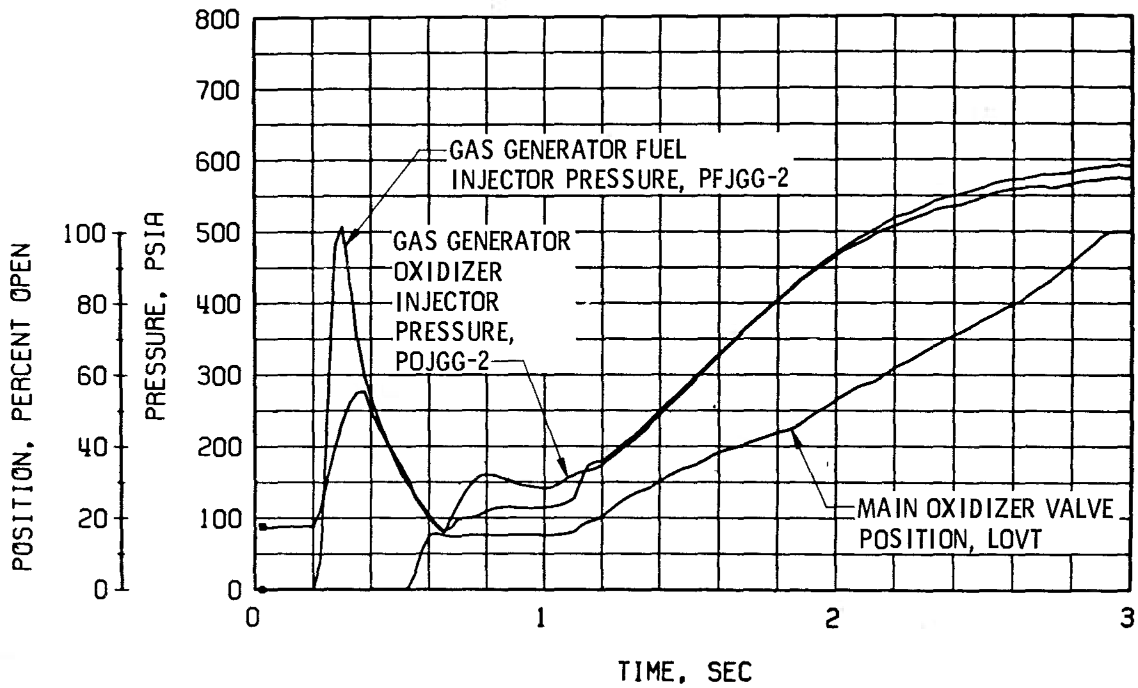


c. Thrust Chamber Fuel System, Shutdown

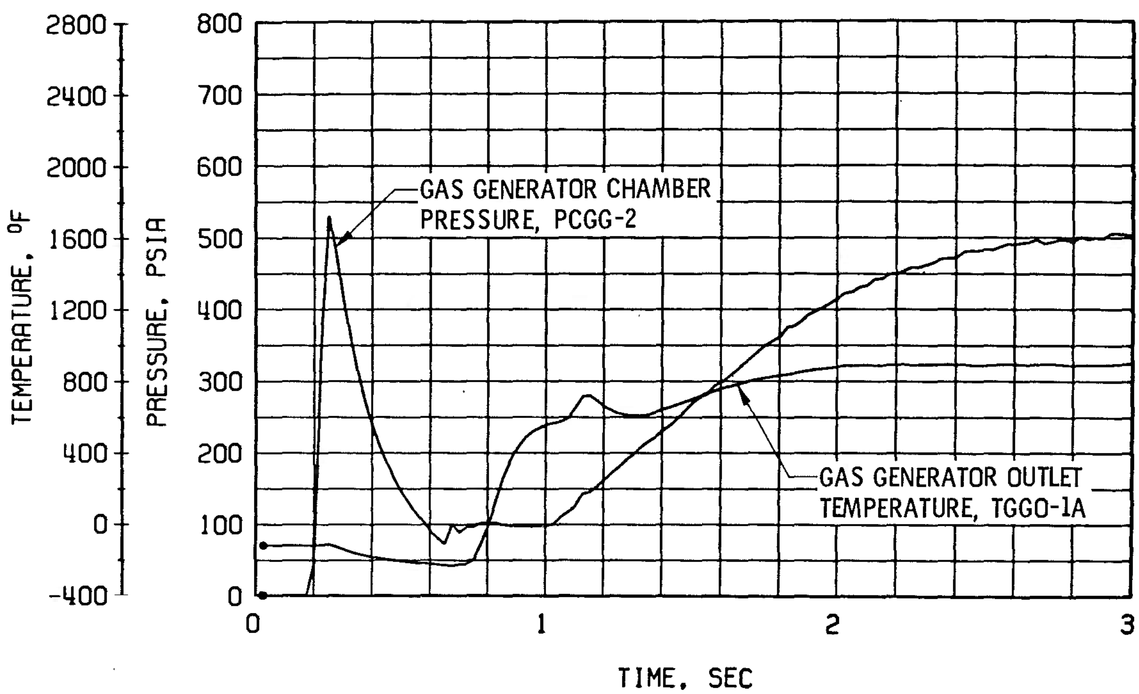


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 20 Continued

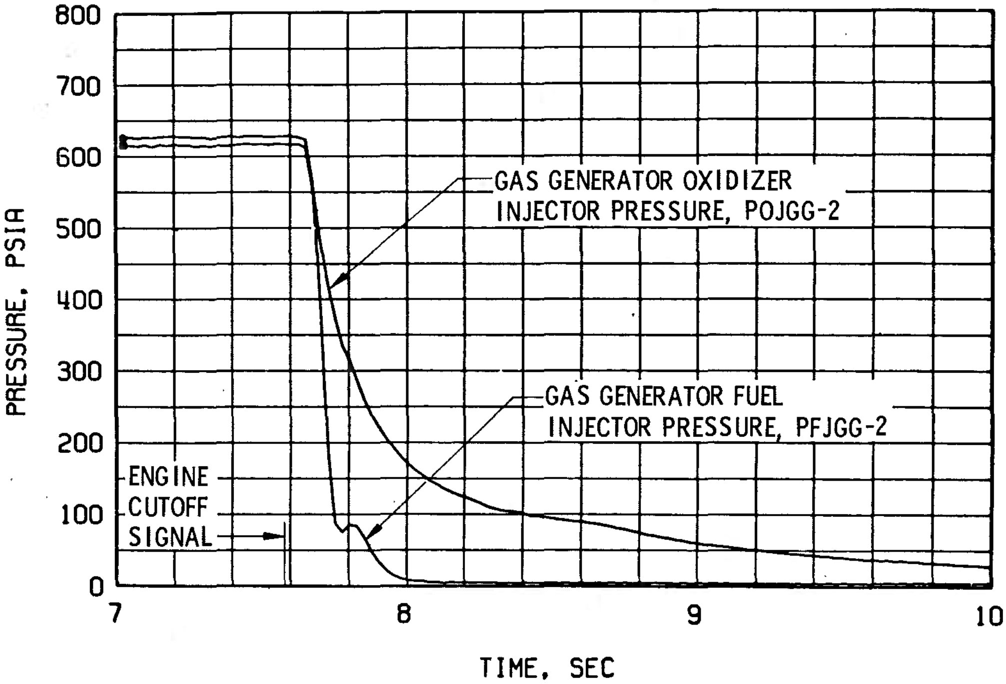


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

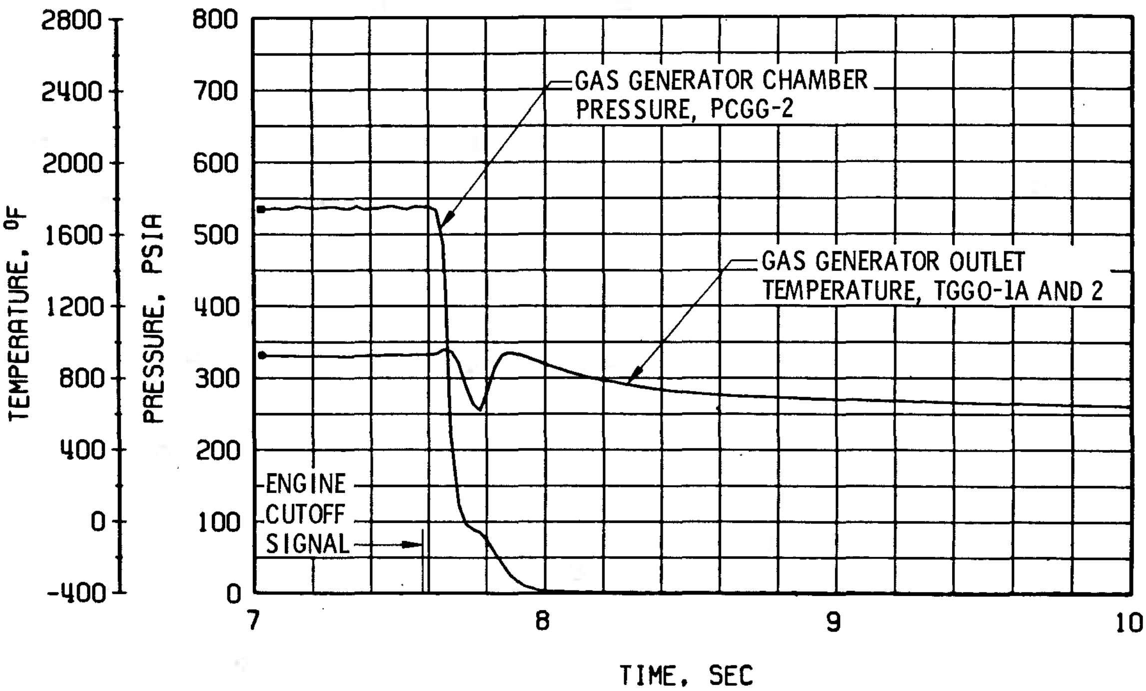


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 20 Continued

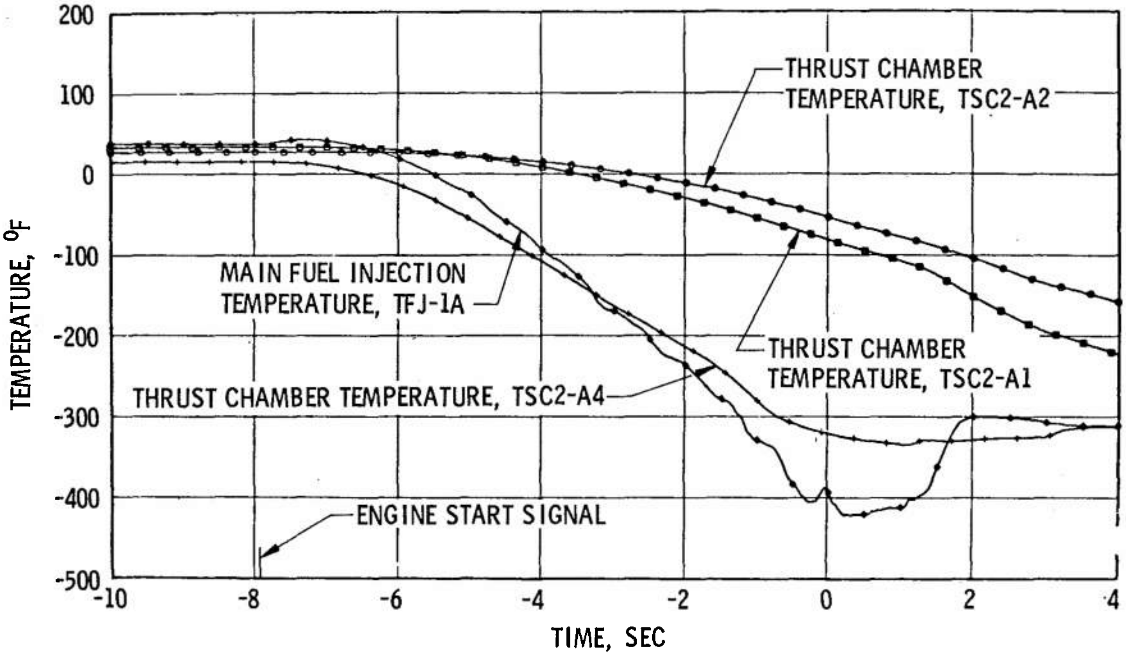


g. Gas Generator Injector Pressures, Shutdown

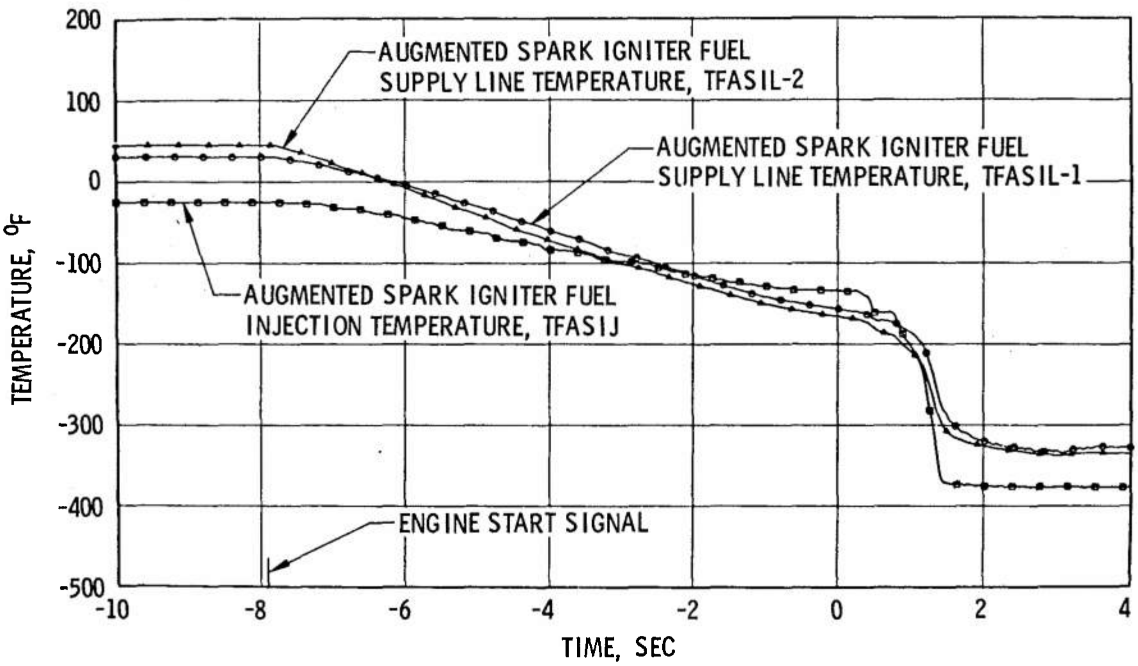


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 20 Continued

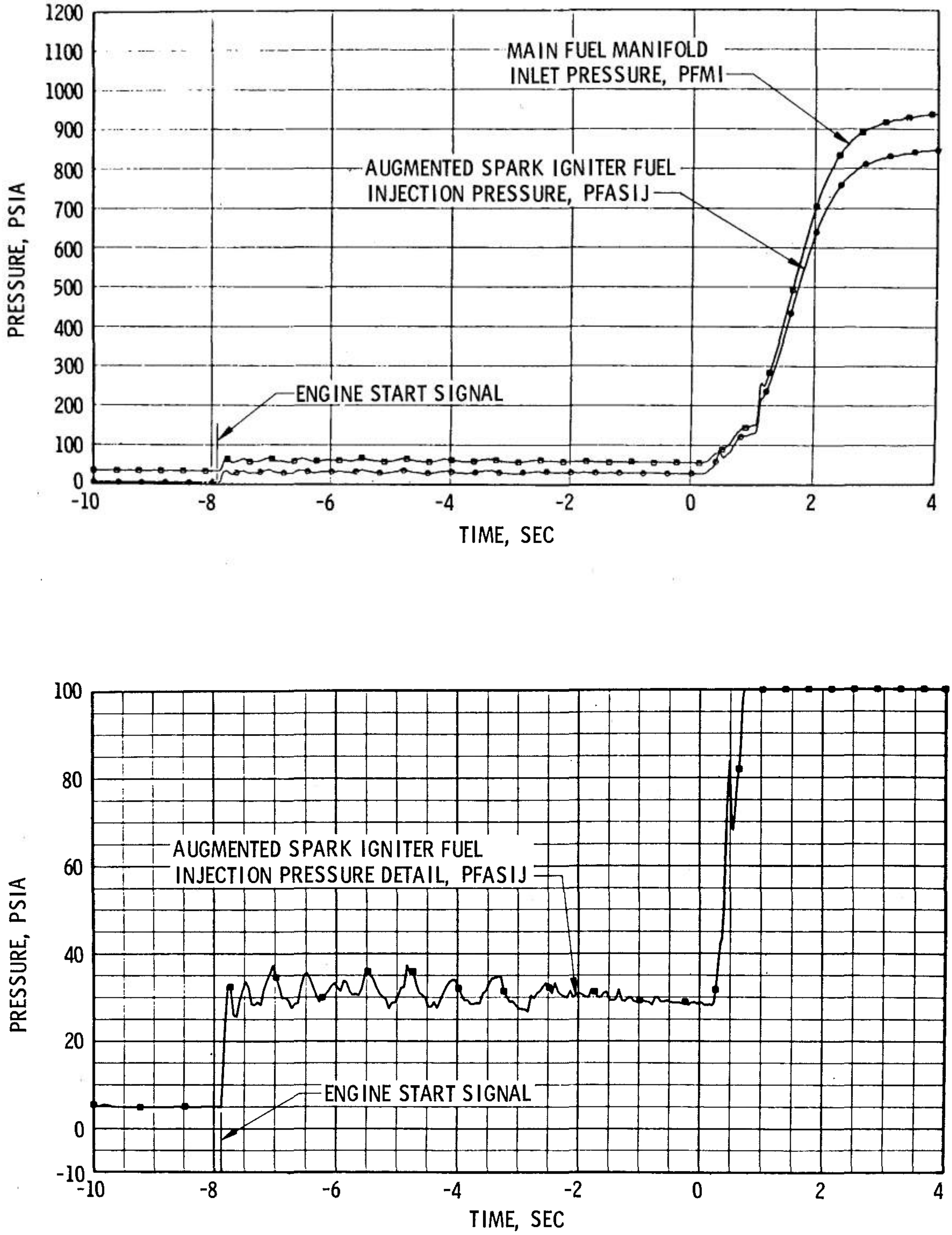


i. Thrust Chamber Temperature Transient, Start



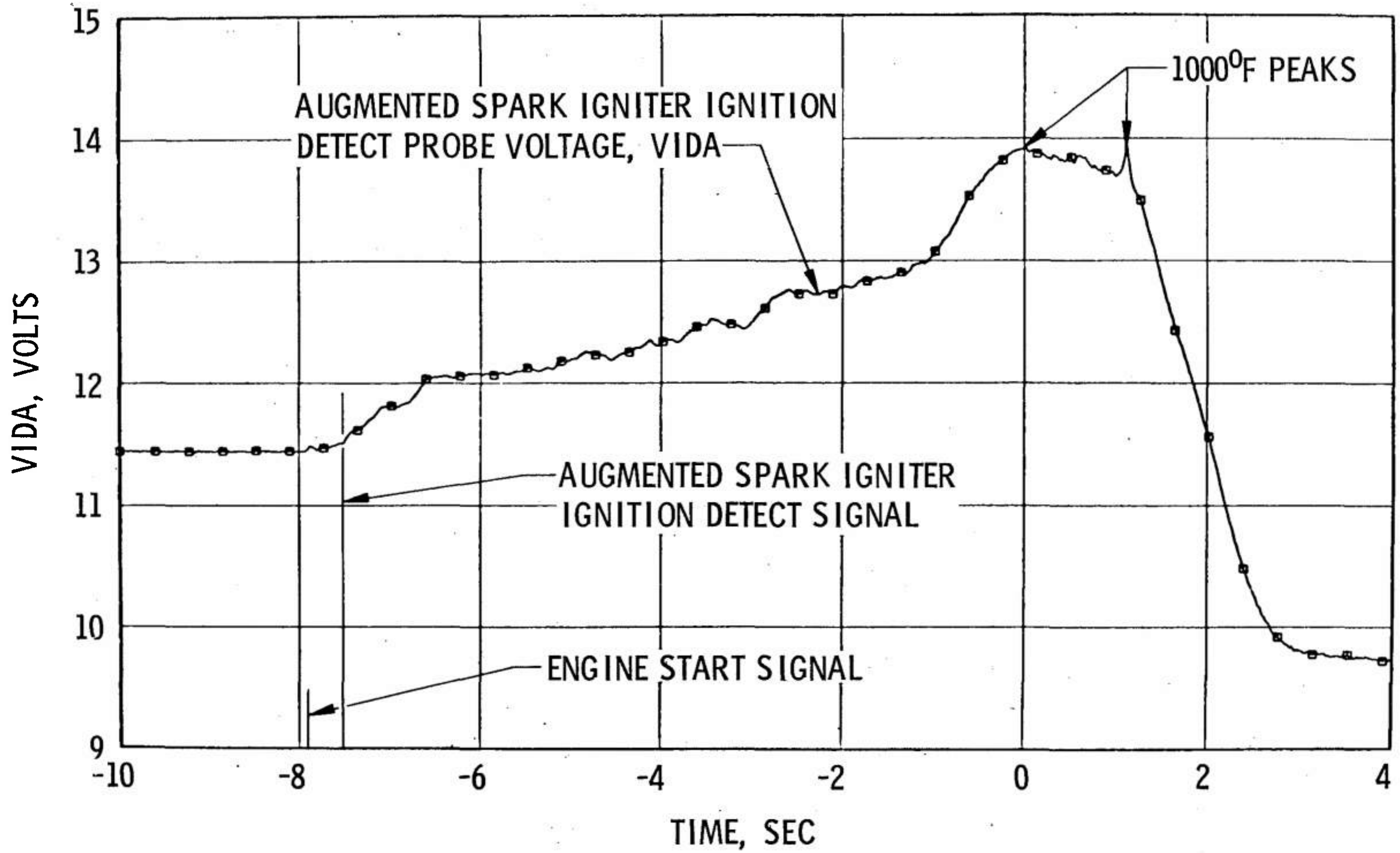
j. Augmented Spark Igniter Fuel Supply Line Temperature Transient, Start

Fig. 20 Continued



k. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

Fig. 20 Continued



l. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 20 Concluded

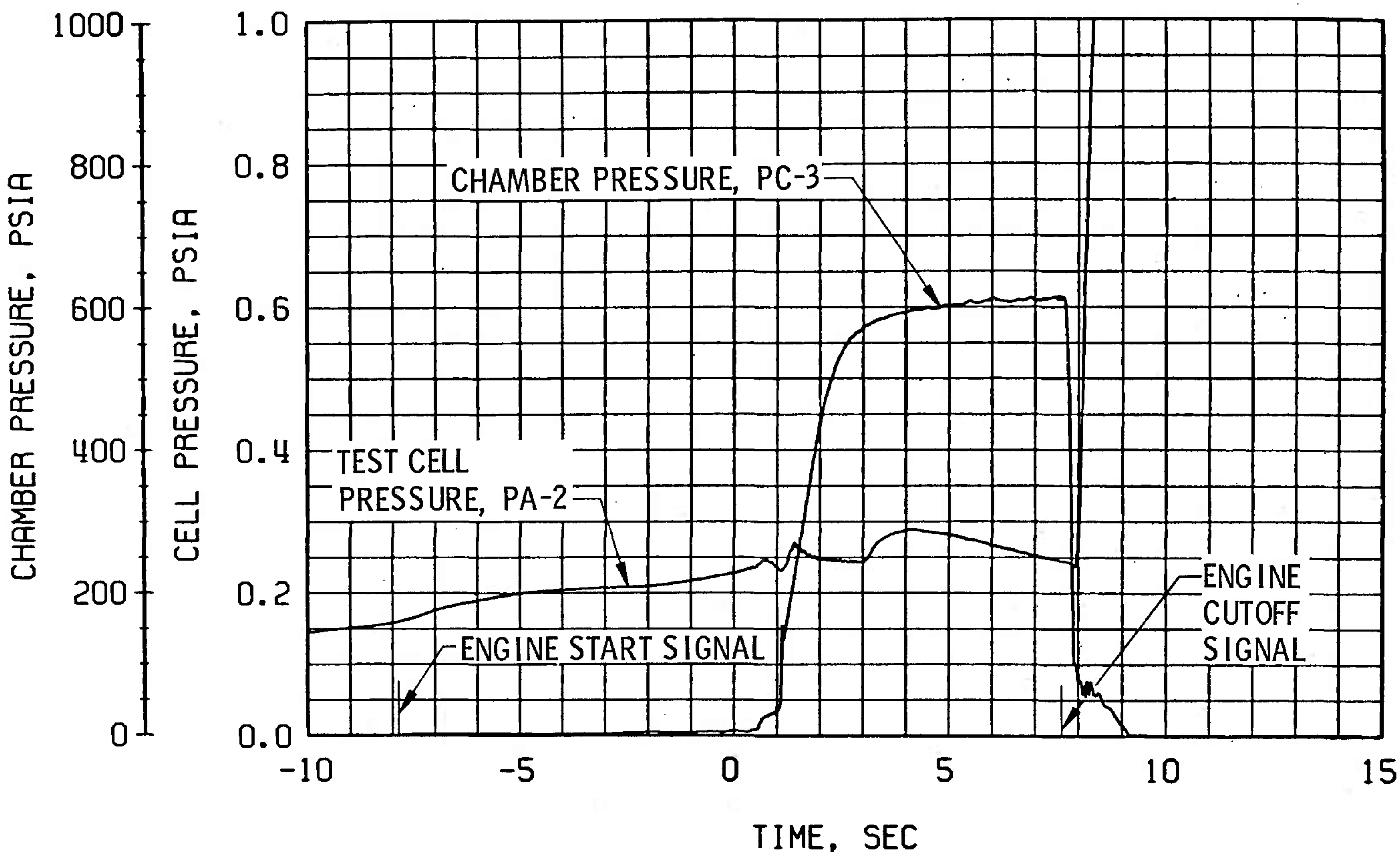


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 39C

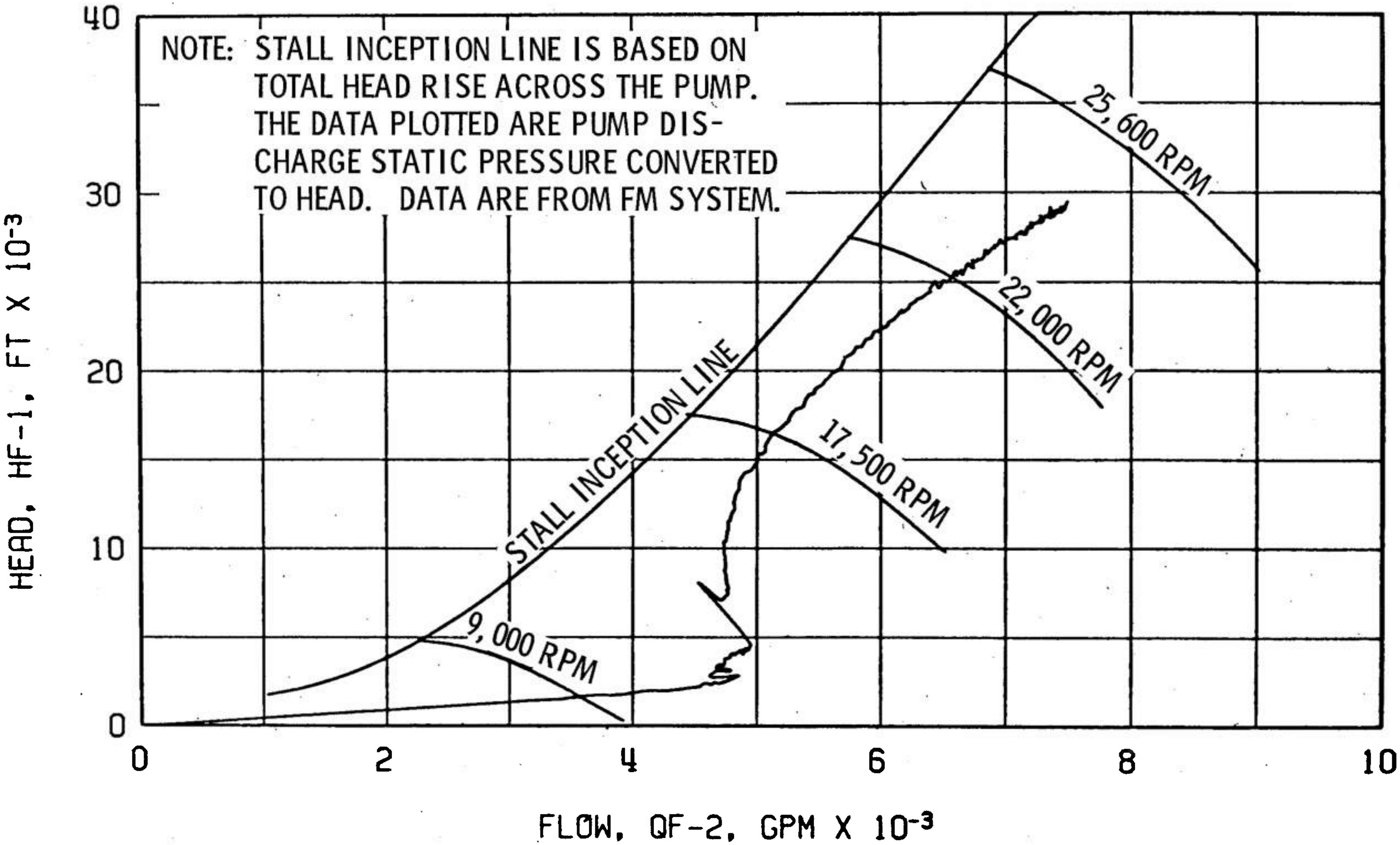
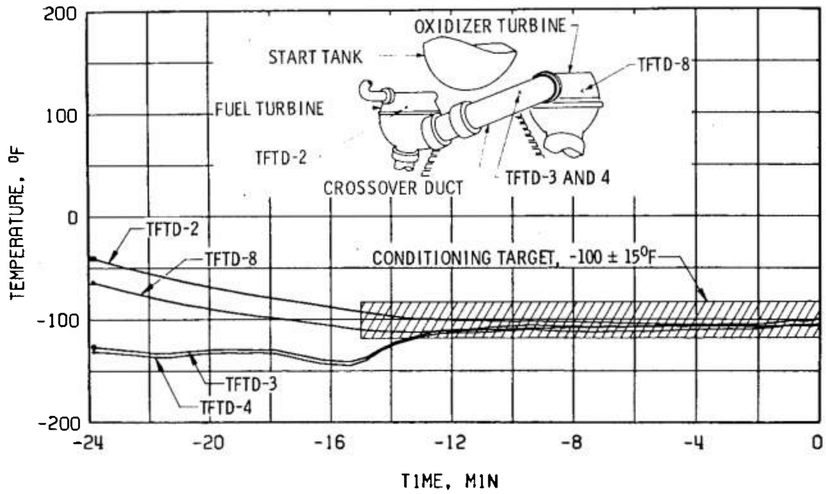
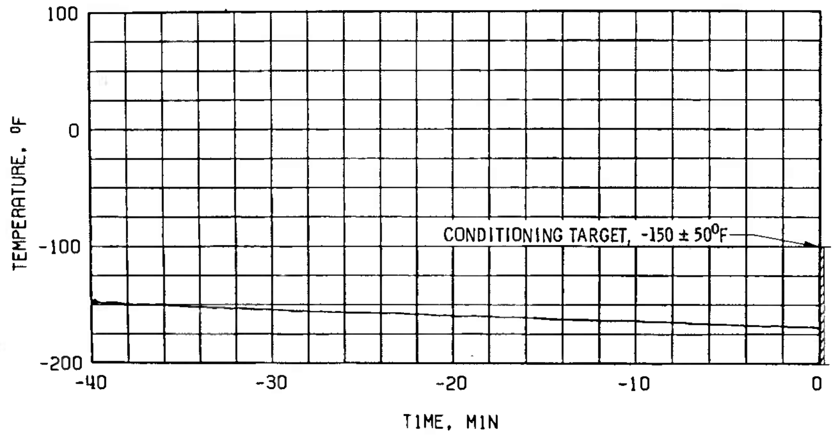


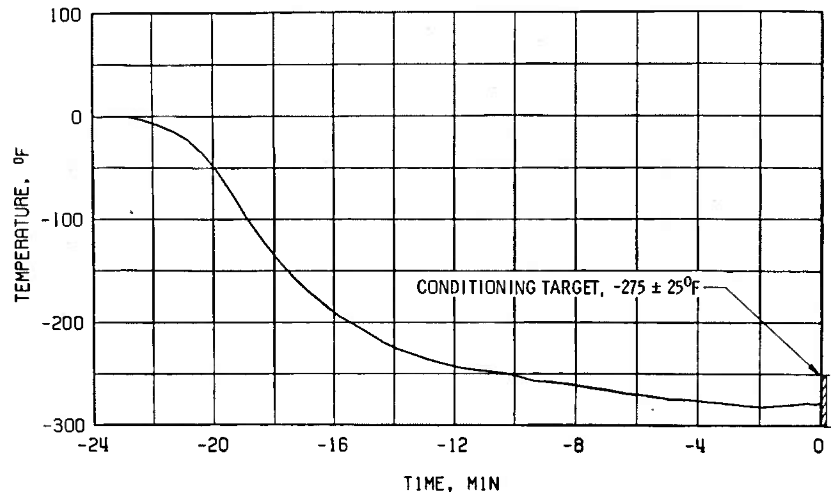
Fig. 22 Fuel Pump Start Transient Performance, Firing 39C



a. Crossover Duct, TFTD

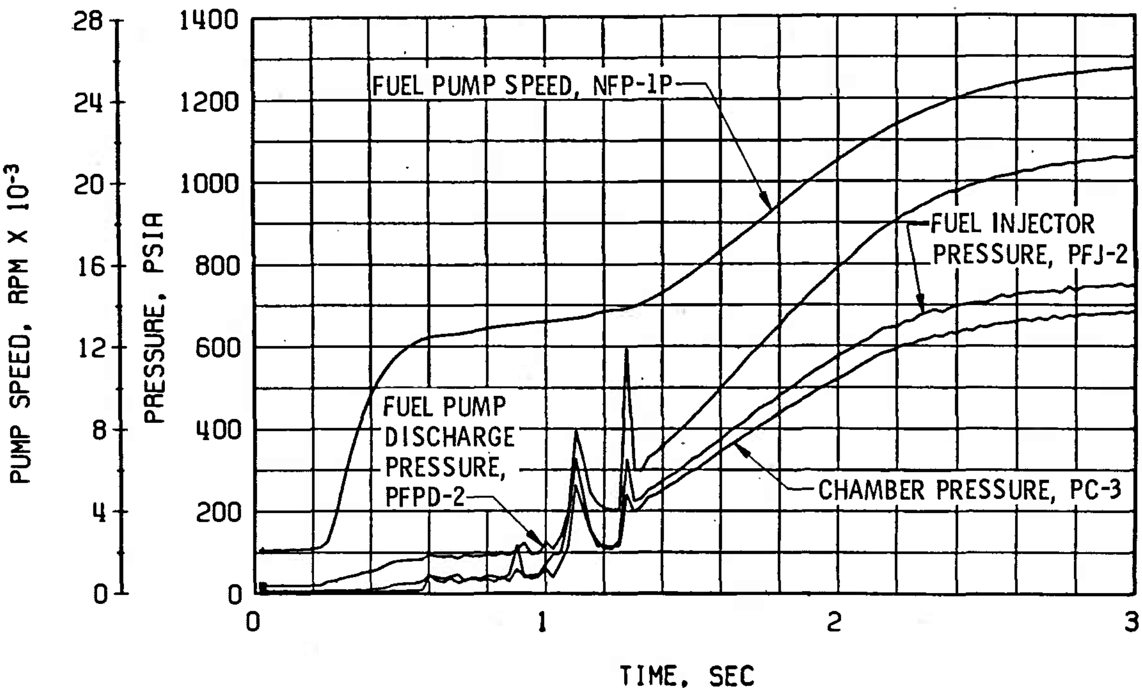


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

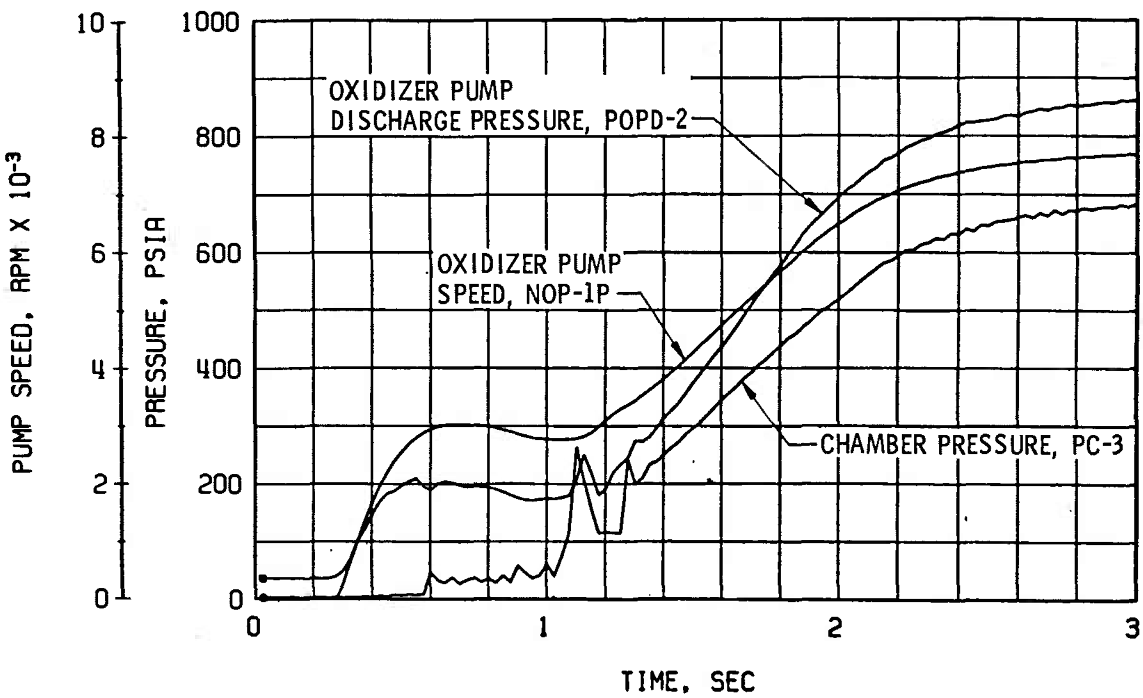


c. Thrust Chamber Throat, TTC-1P

Fig. 23 Thermal Conditioning History of Engine Components, Firing 39D

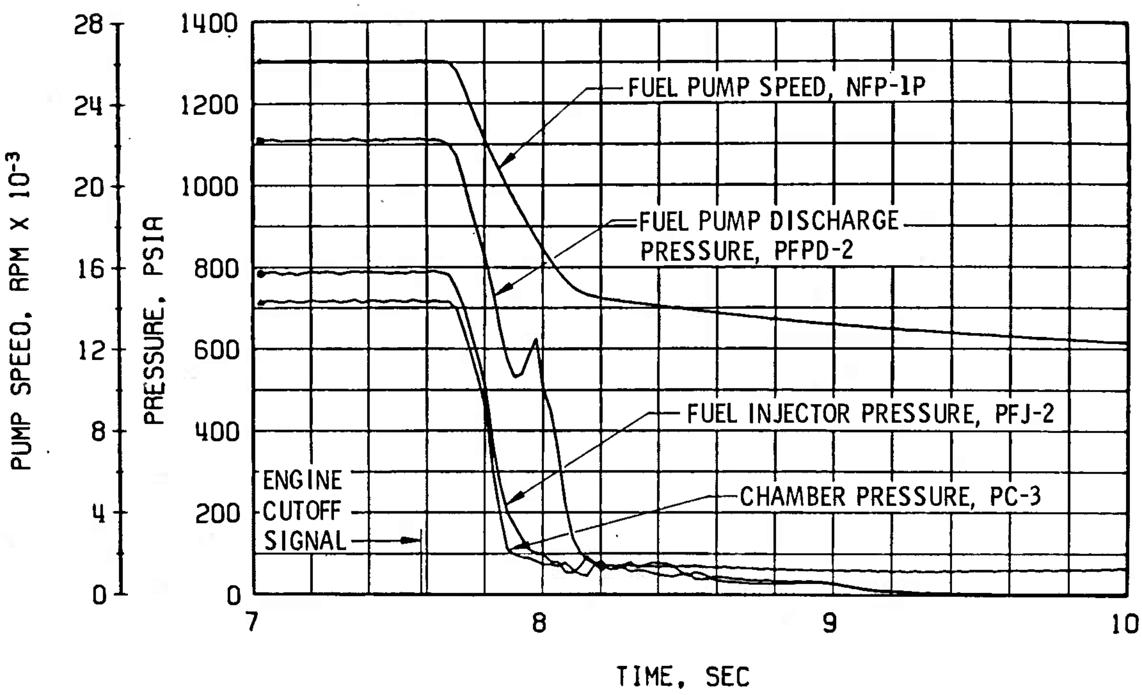


a. Thrust Chamber Fuel System, Start

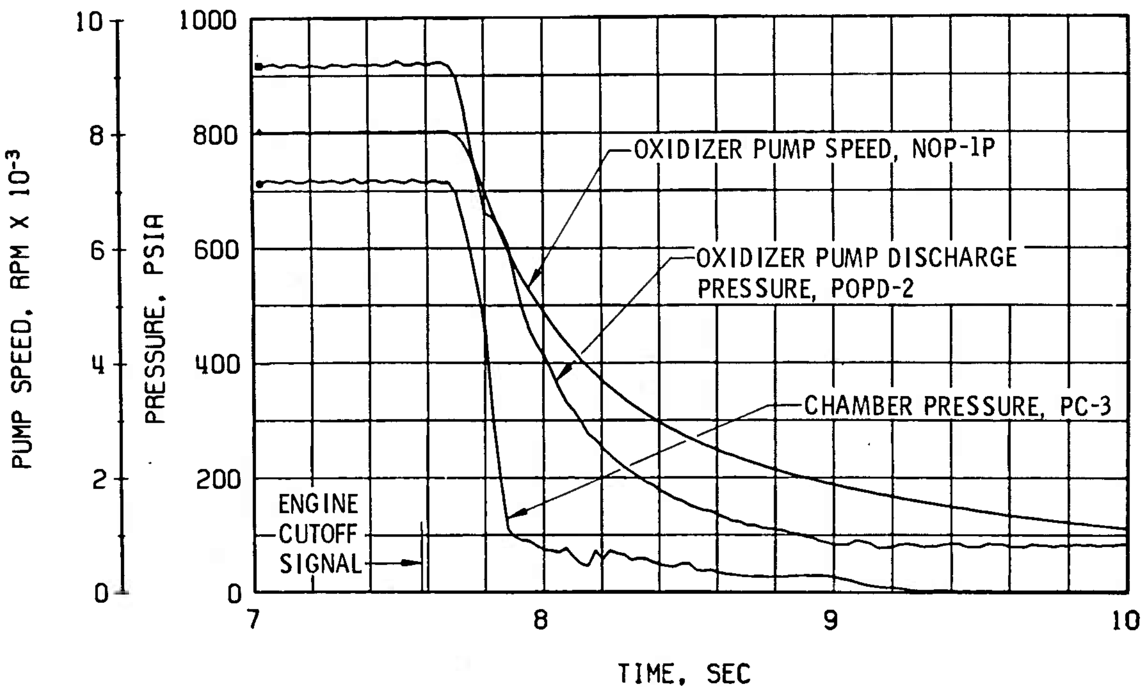


b. Thrust Chamber Oxidizer System, Start

Fig. 24 Engine Transient Operation, Firing 39D

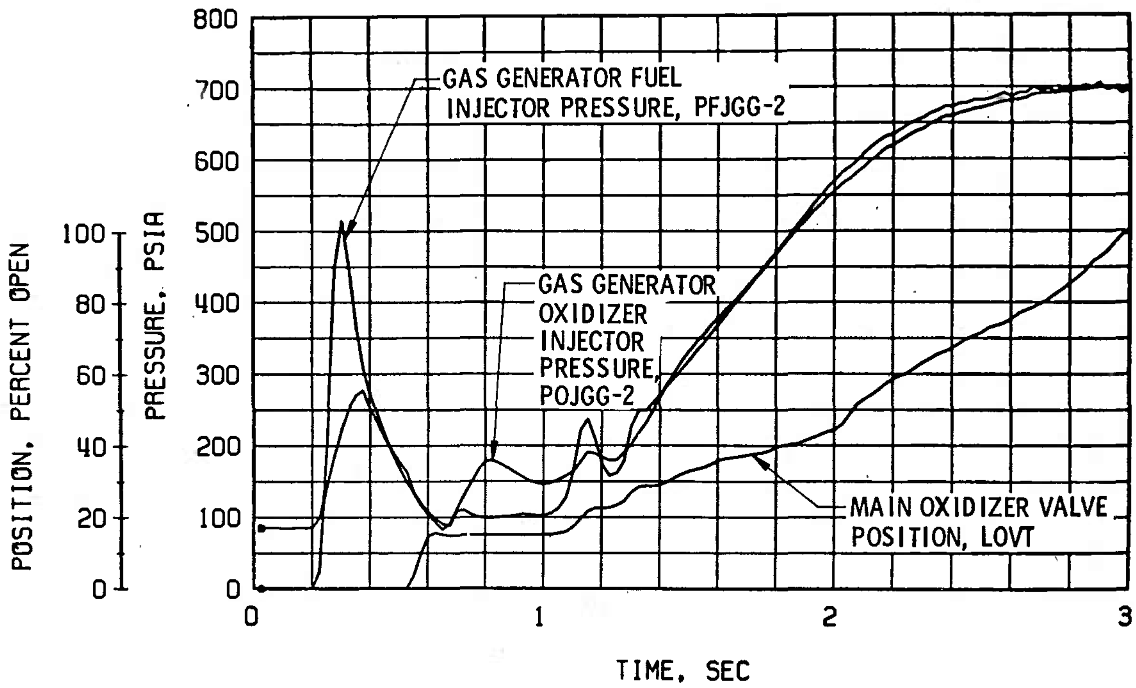


c. Thrust Chamber Fuel System, Shutdown

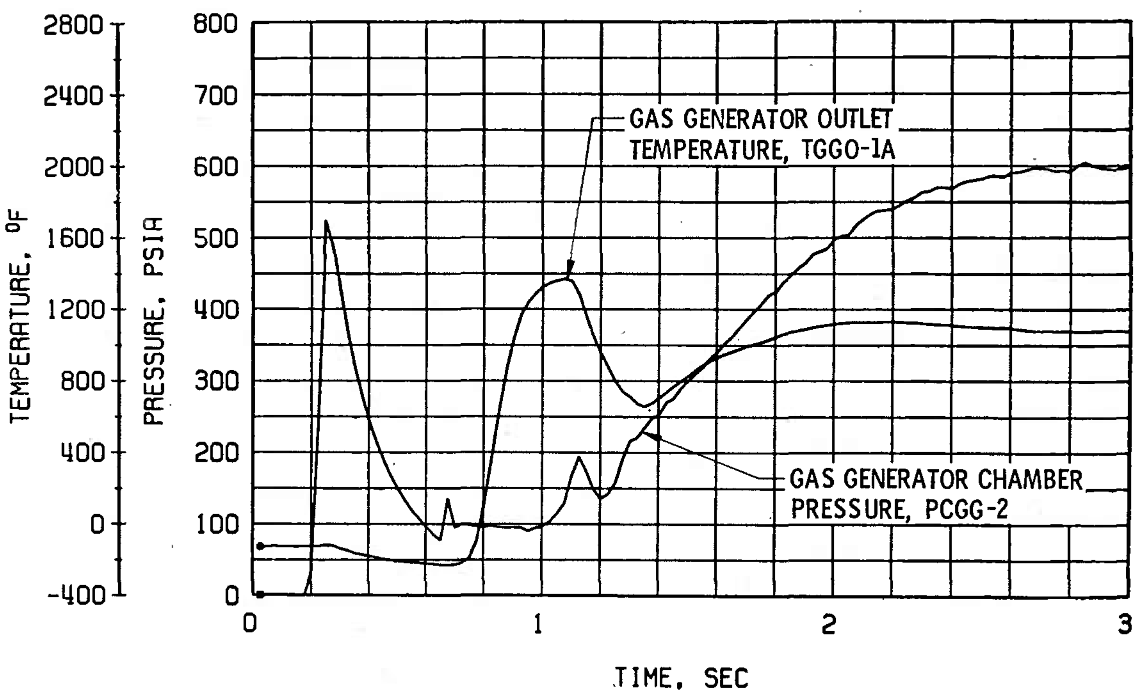


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 24 Continued

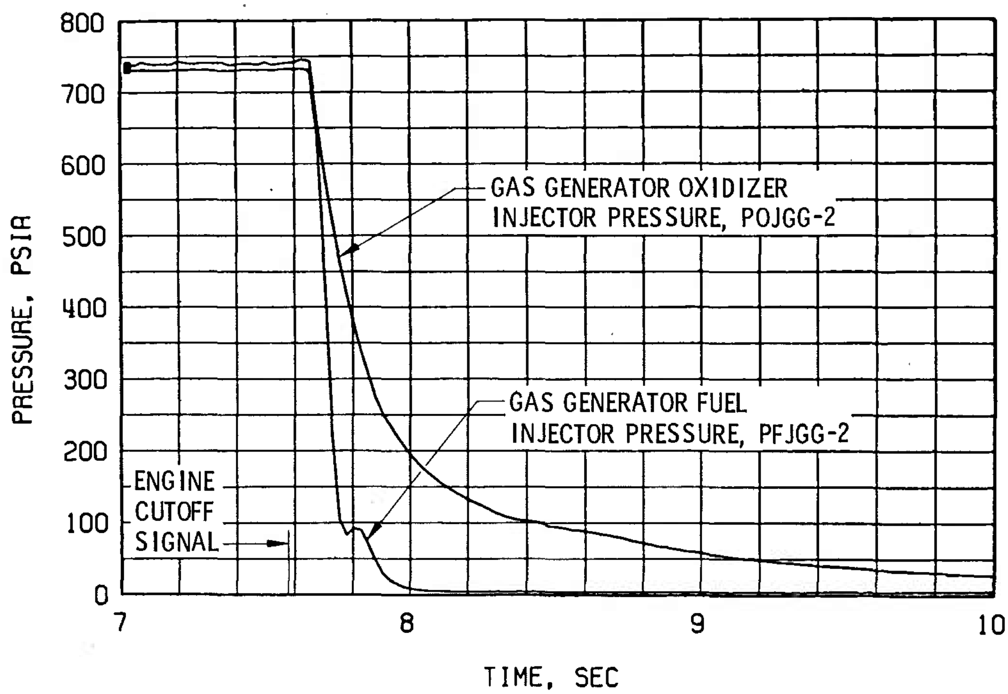


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

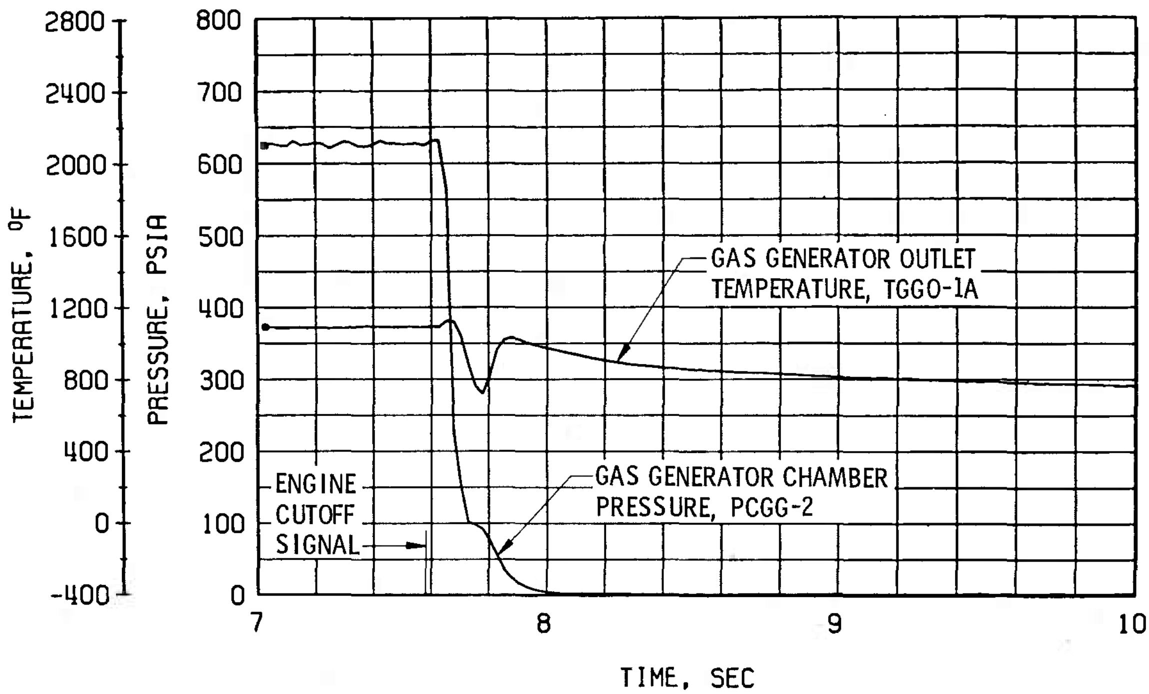


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 24 Continued

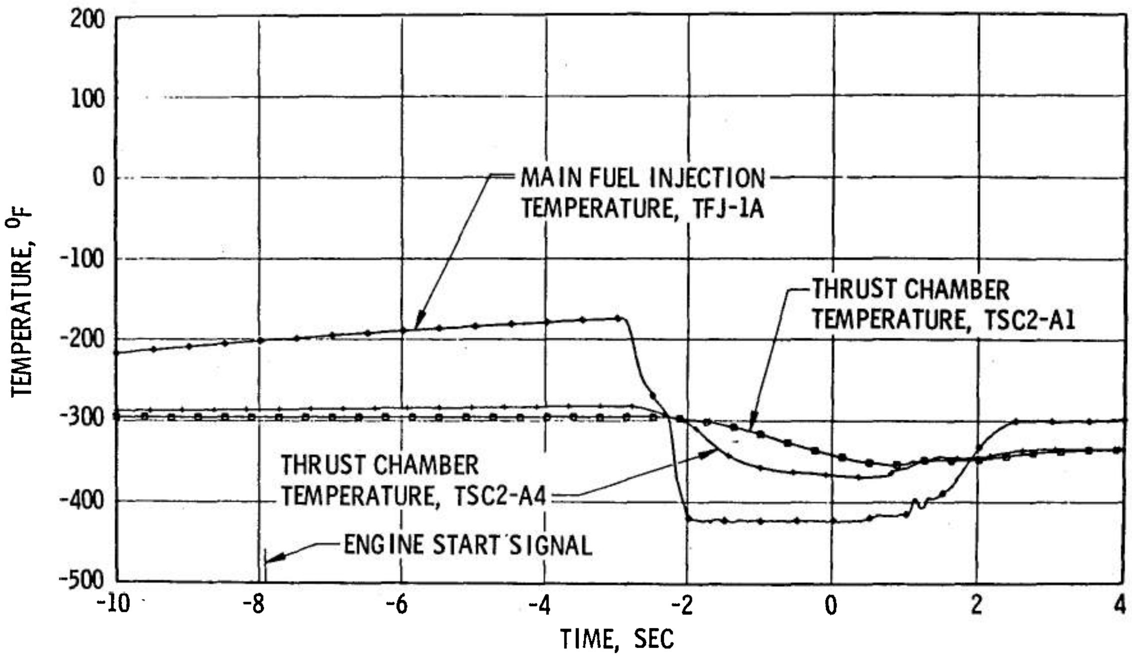


g. Gas Generator Injector Pressures, Shutdown

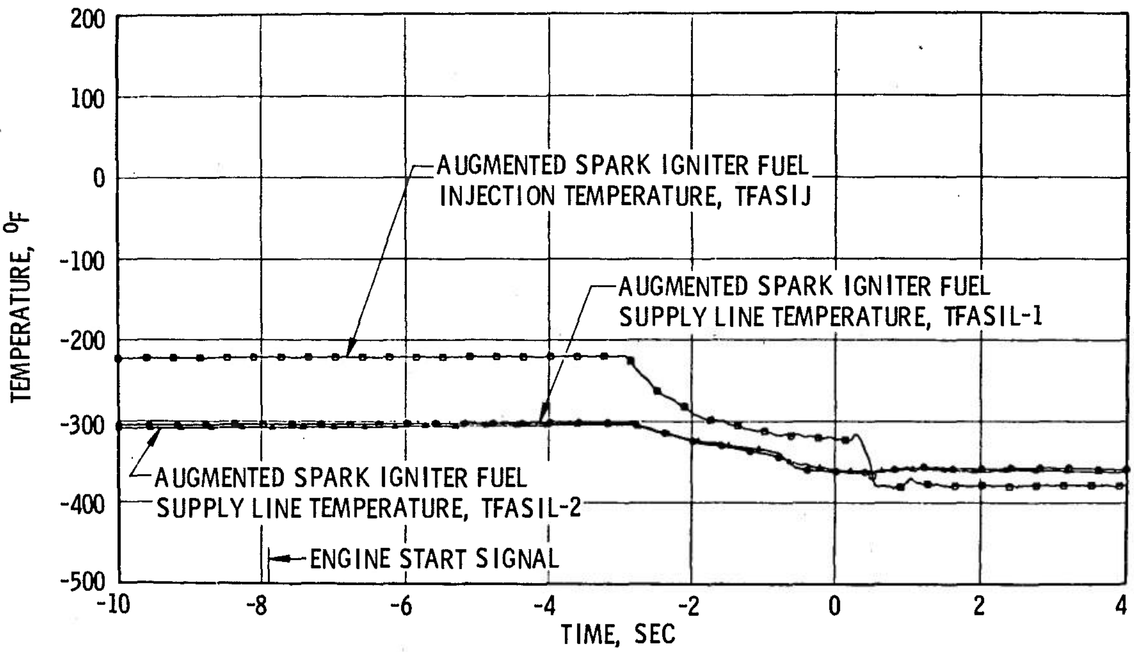


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 24 Continued

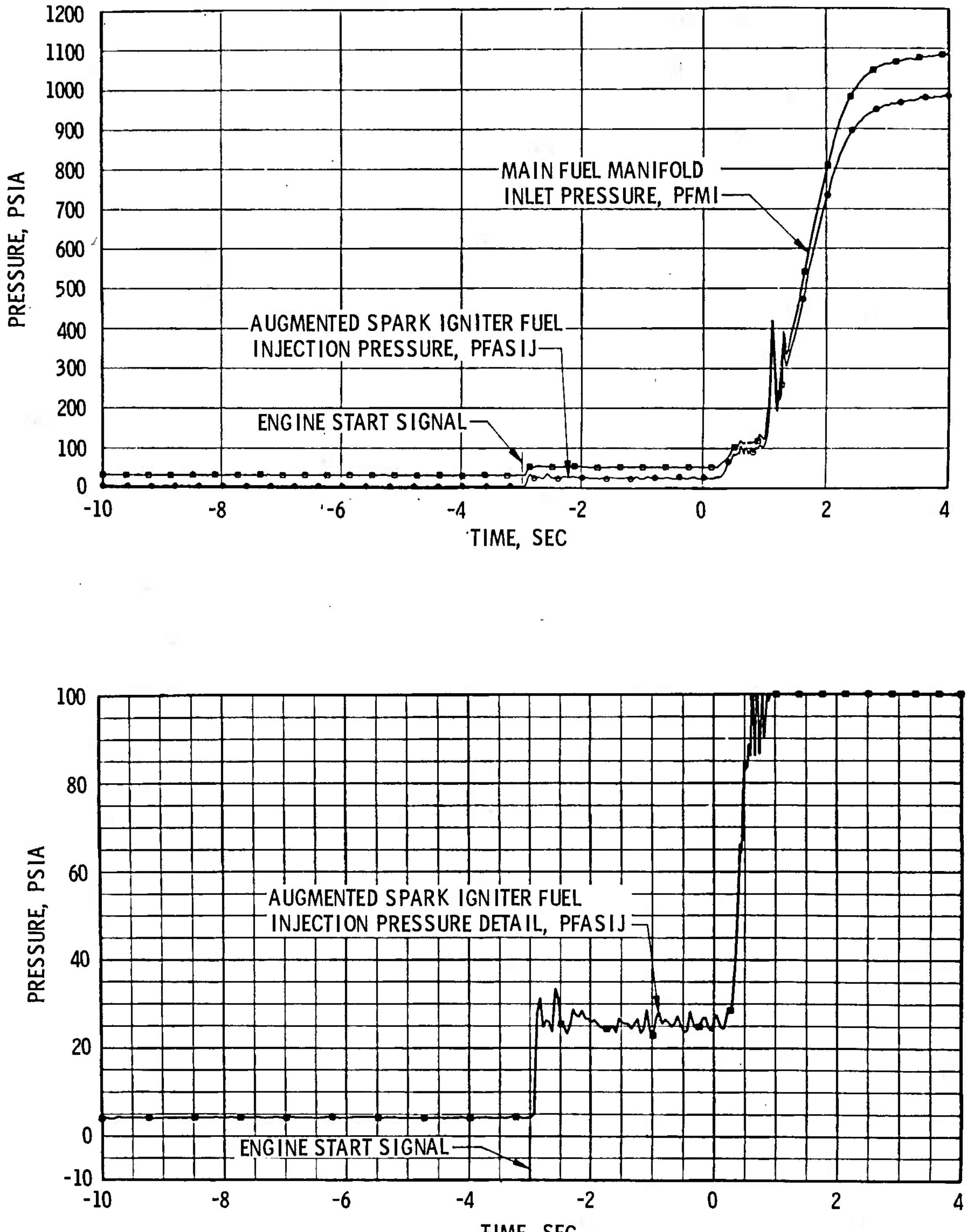


i. **Thrust Chamber Temperature Transient, Start**



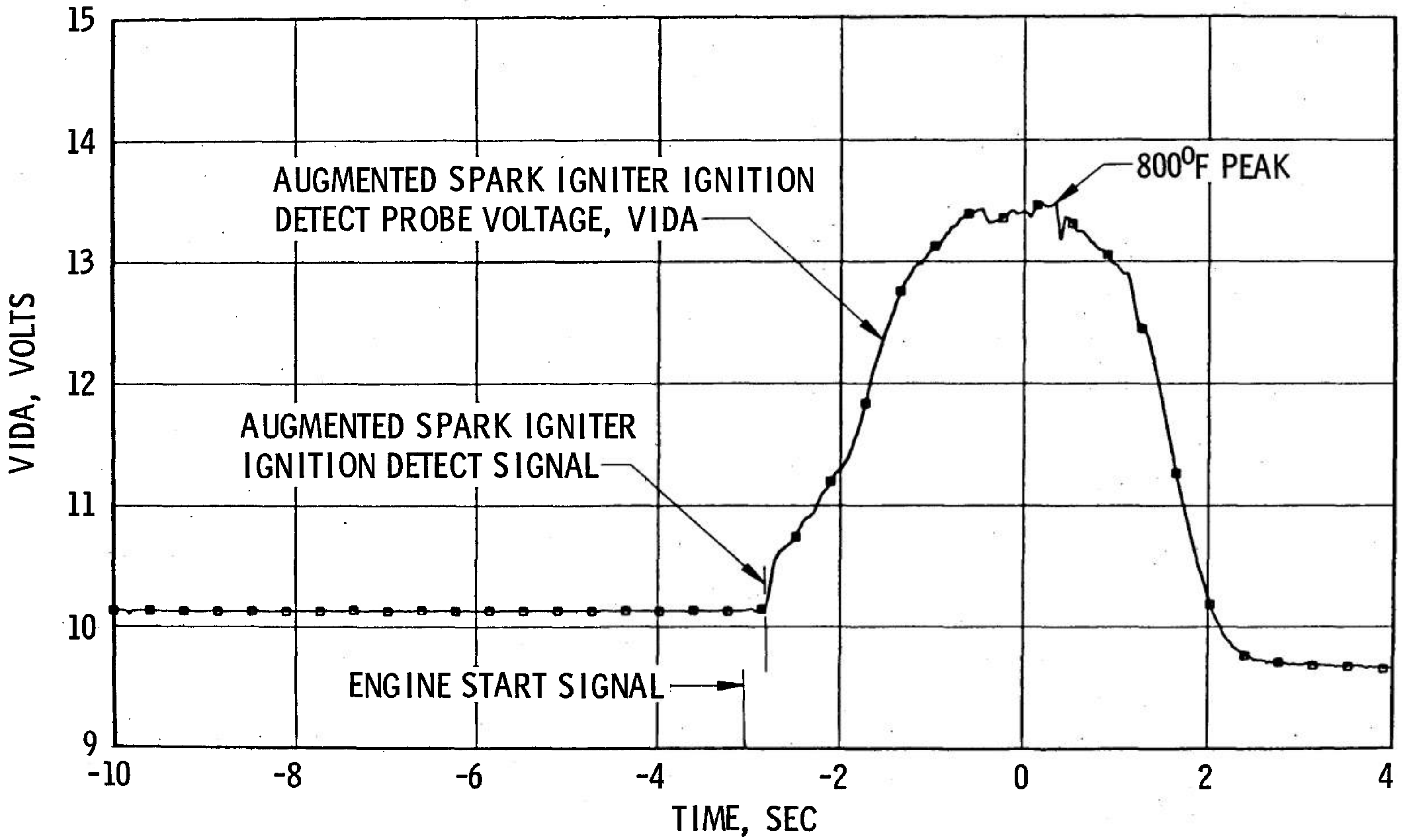
j. **Augmented Spark Igniter Fuel Supply Line Temperature Transient, Start**

Fig. 24 Continued



k. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

Fig. 24 Continued



I. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 24 Concluded

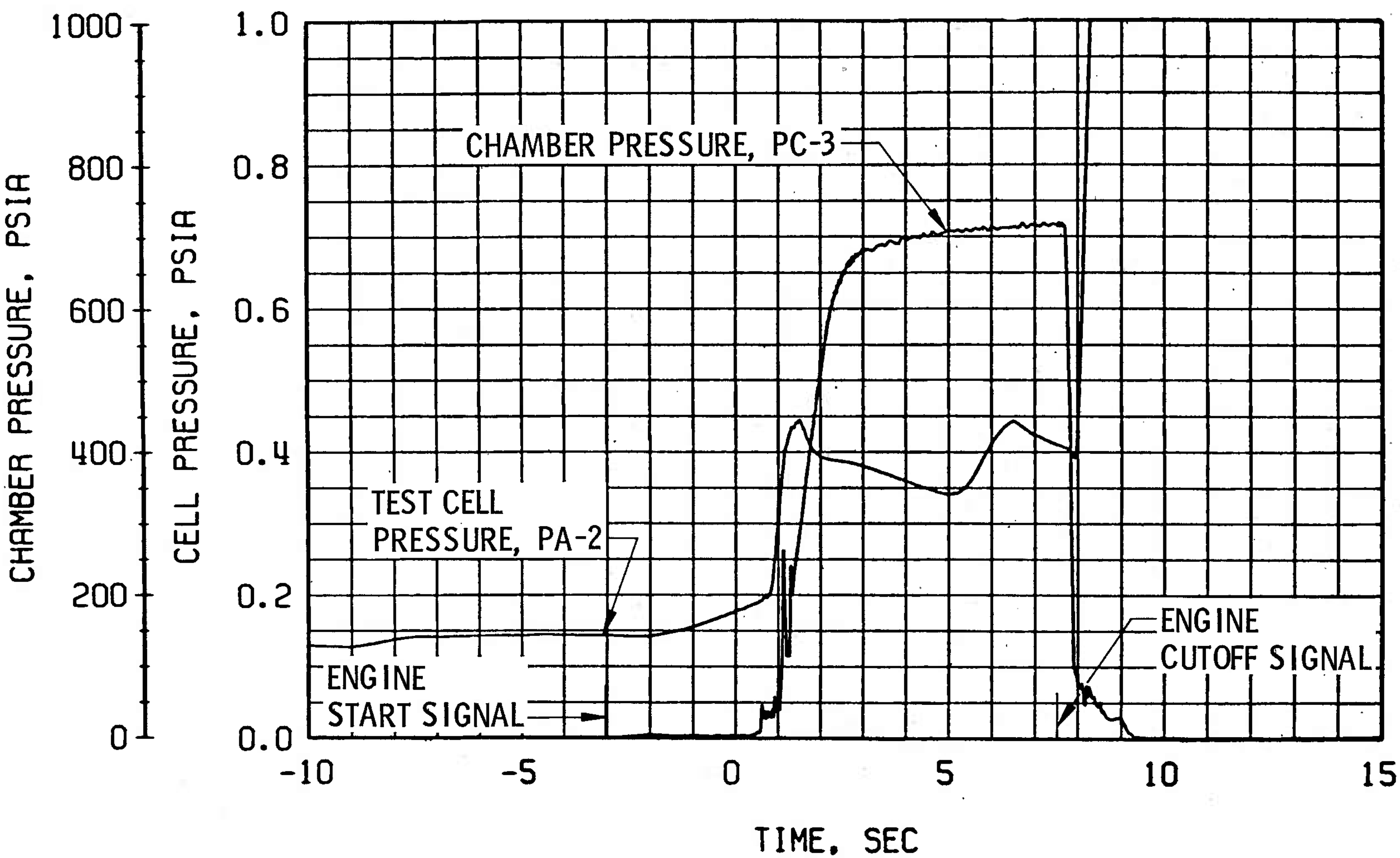
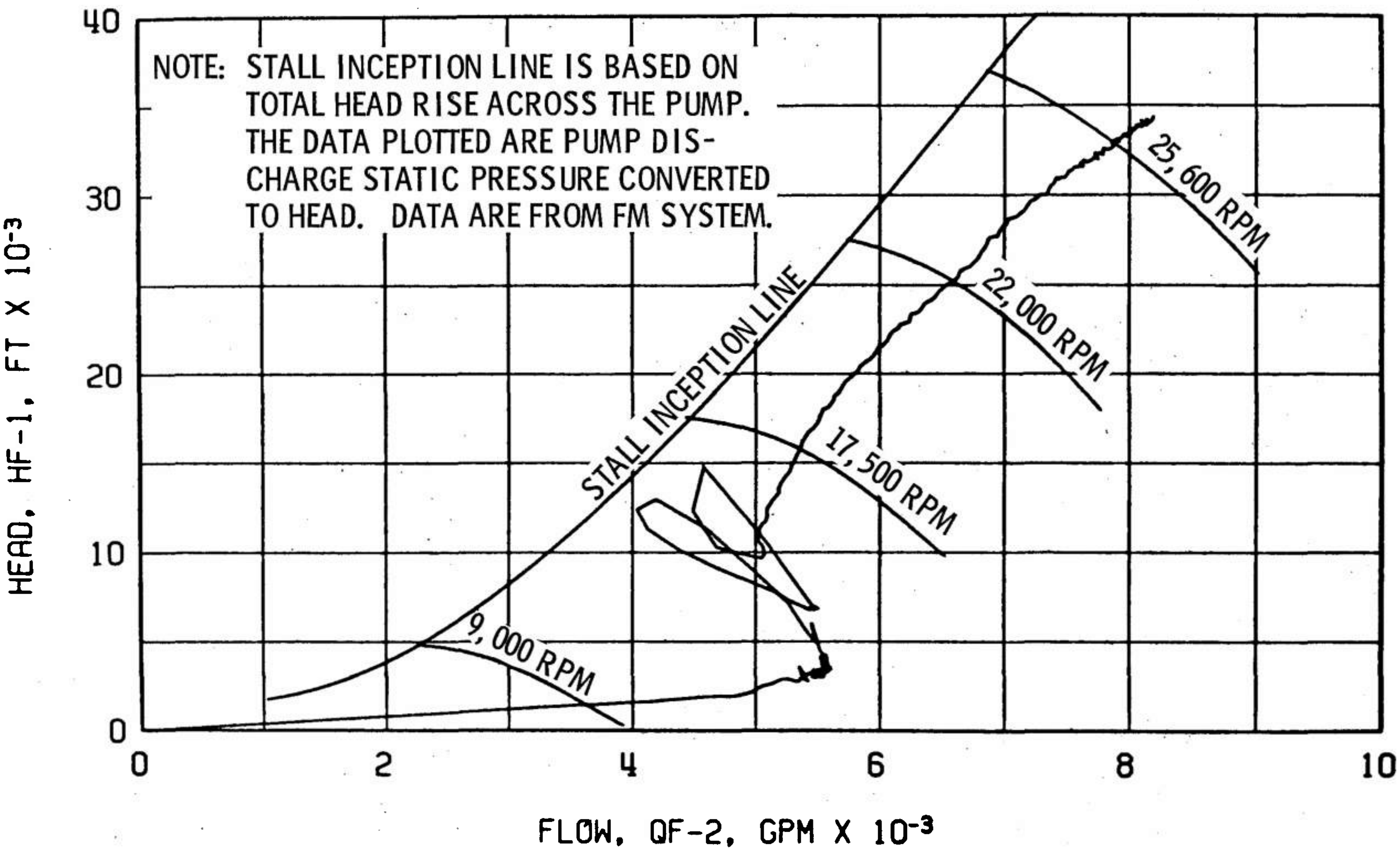
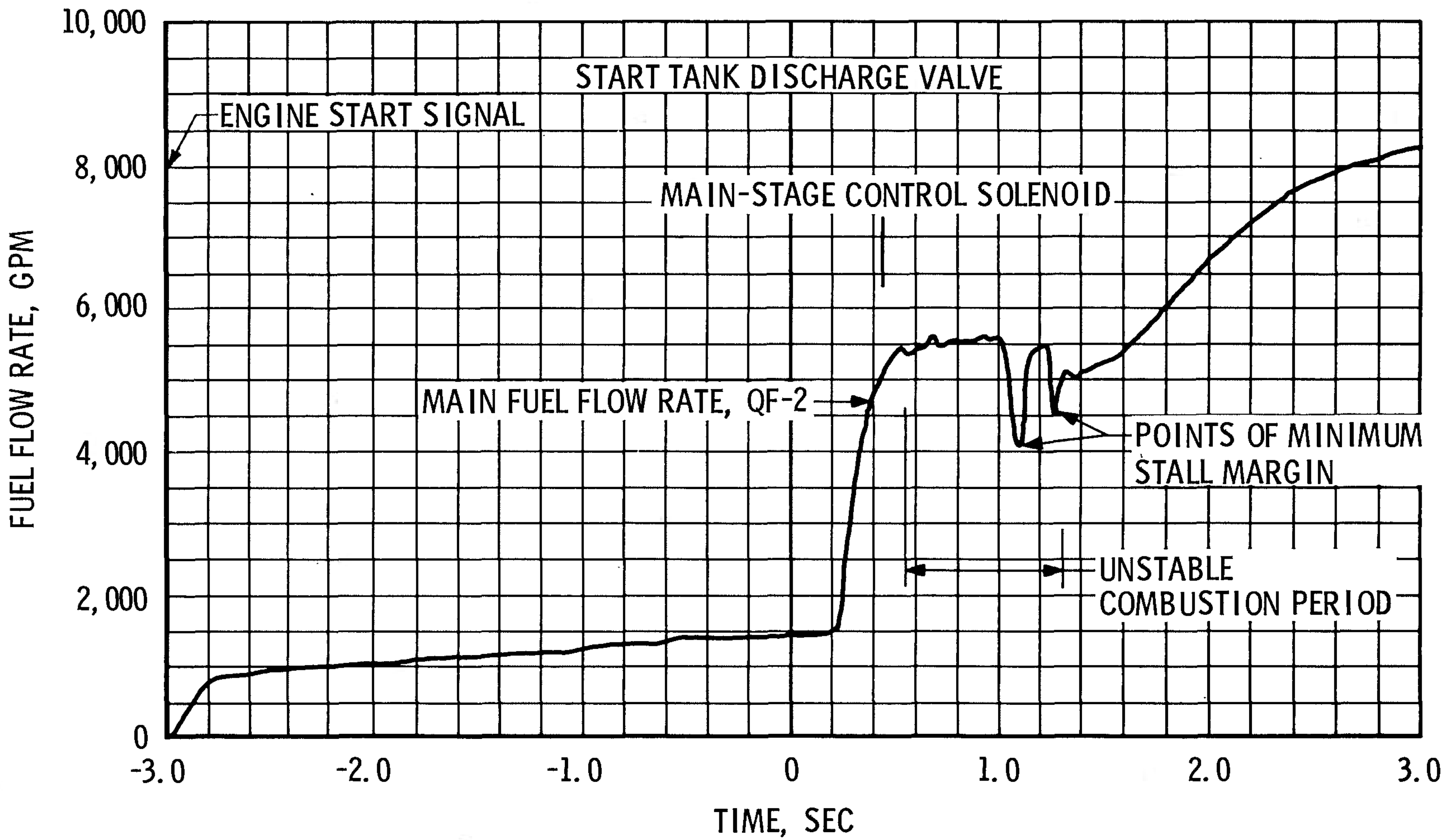


Fig. 25 Engine Ambient and Combustion Chamber Pressures, Firing 39D



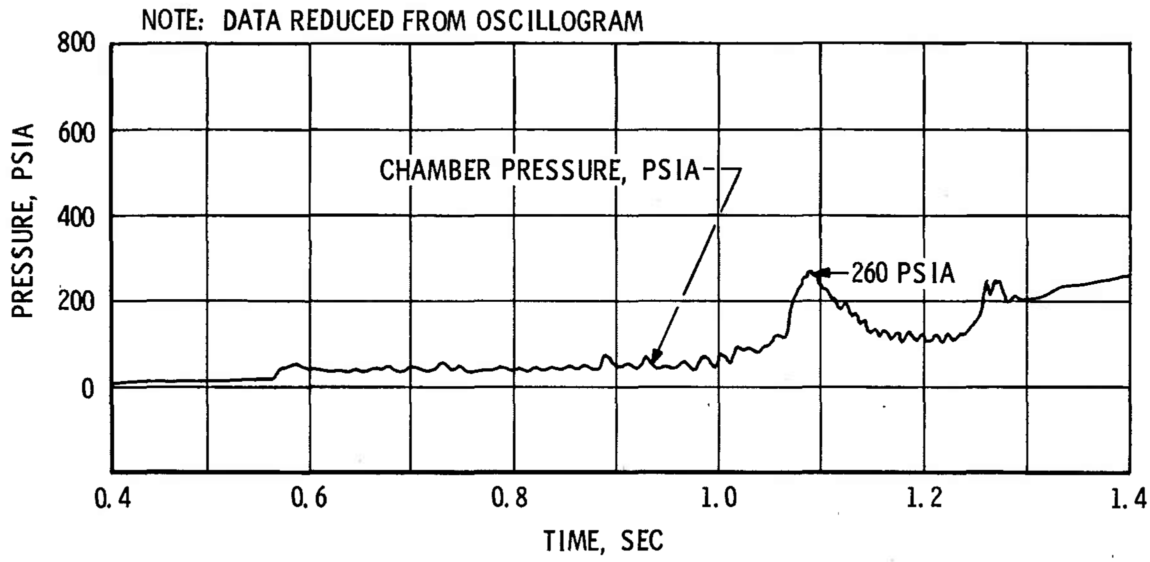
a. Fuel Pump Head versus Flow

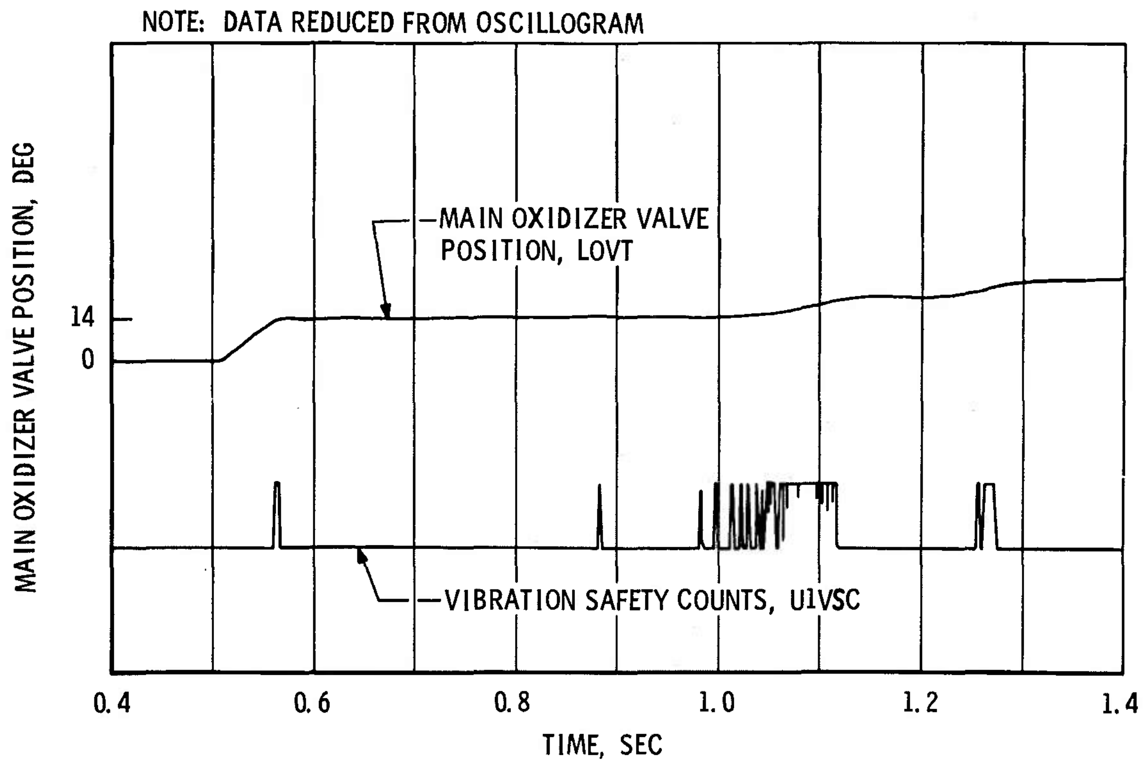
Fig. 26 Fuel Pump Start Transient Performance and Thrust Chamber Combustion Instability, Firing 39D



b. Fuel Flow Rate, QF-2, versus Time, Firing 39D, Start

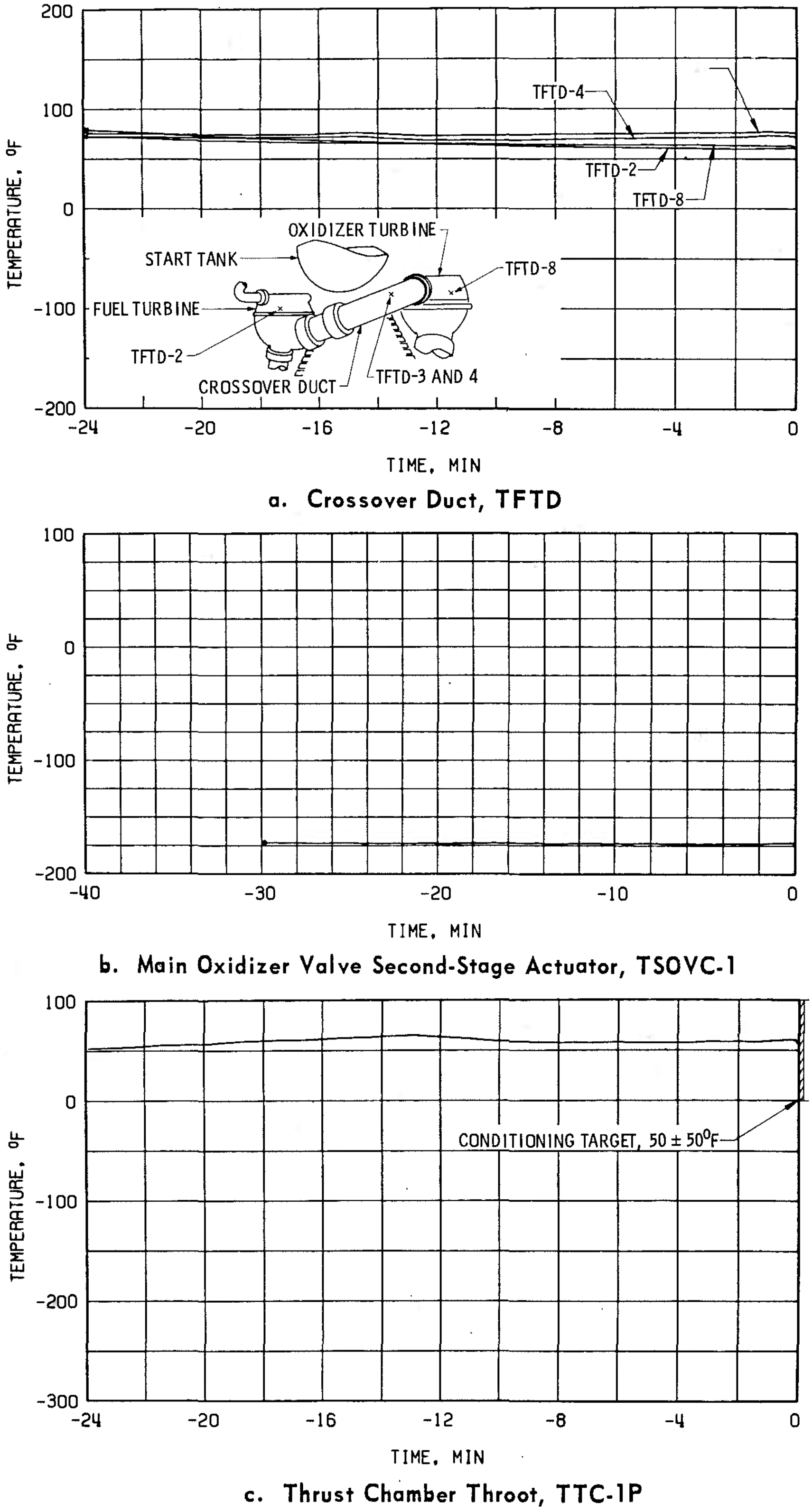
Fig. 26 Continued





c. Thrust Chamber Ignition Transient Combustion Instability Details and Main Oxidizer Valve Position

Fig. 26 Concluded

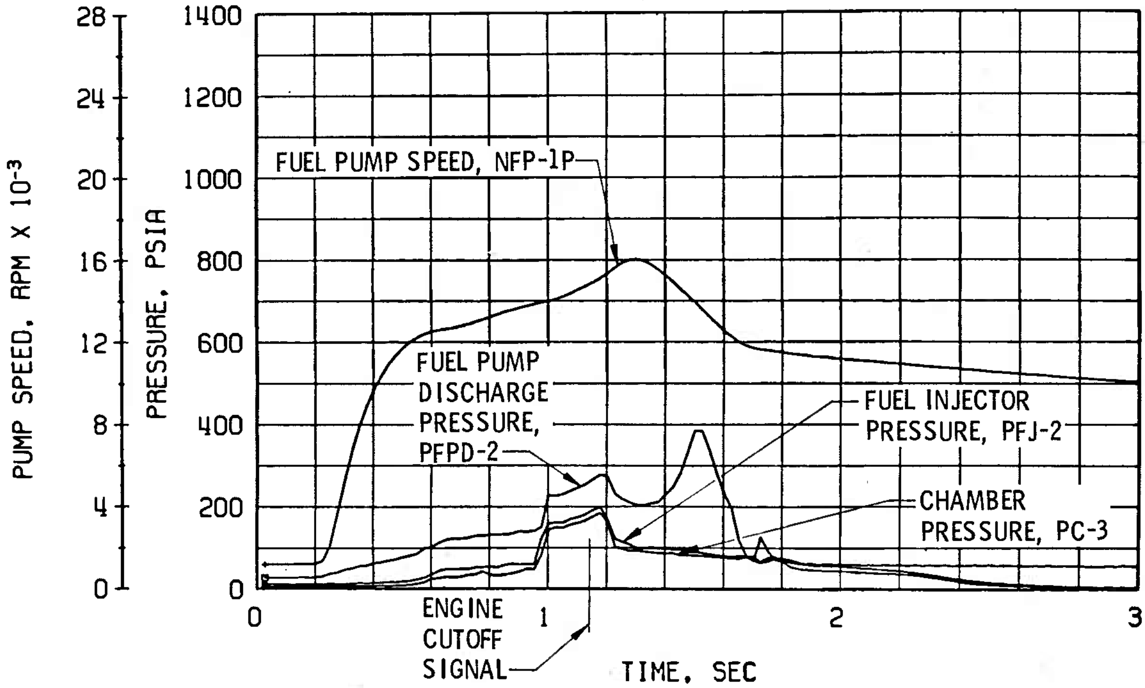


a. Crossover Duct, TFTD

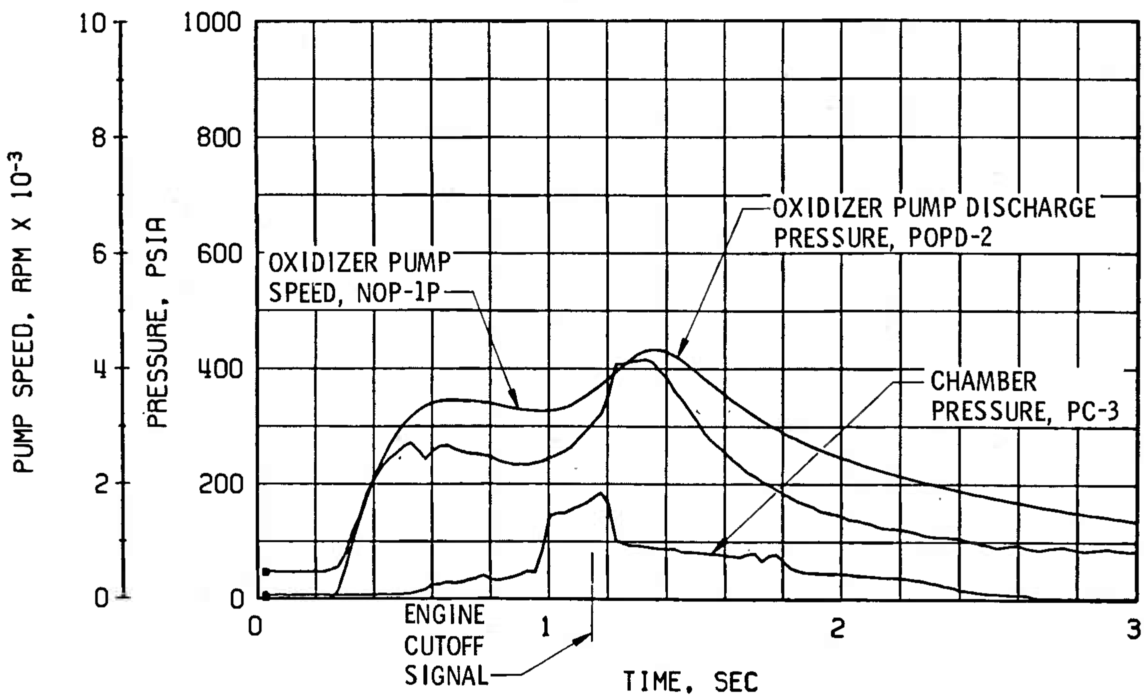
b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

c. Thrust Chamber Throat, TTC-1P

Fig. 27 Thermal Conditioning History of Engine Components, Firing 39E

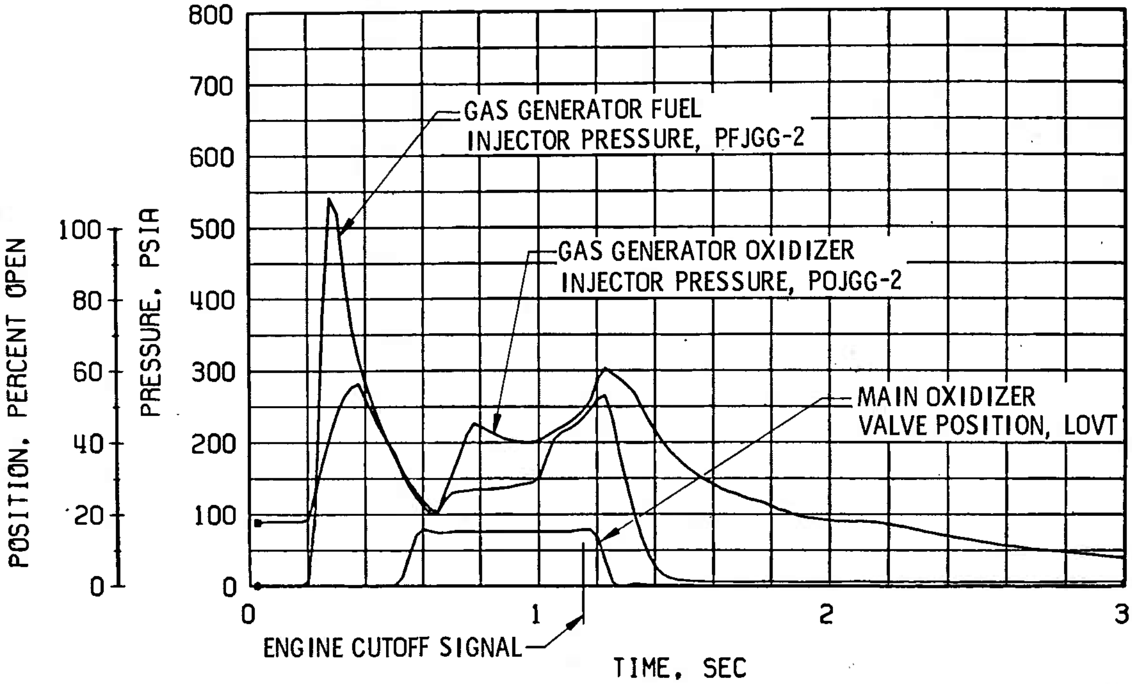


a. Thrust Chamber Fuel System, Start and Shutdown

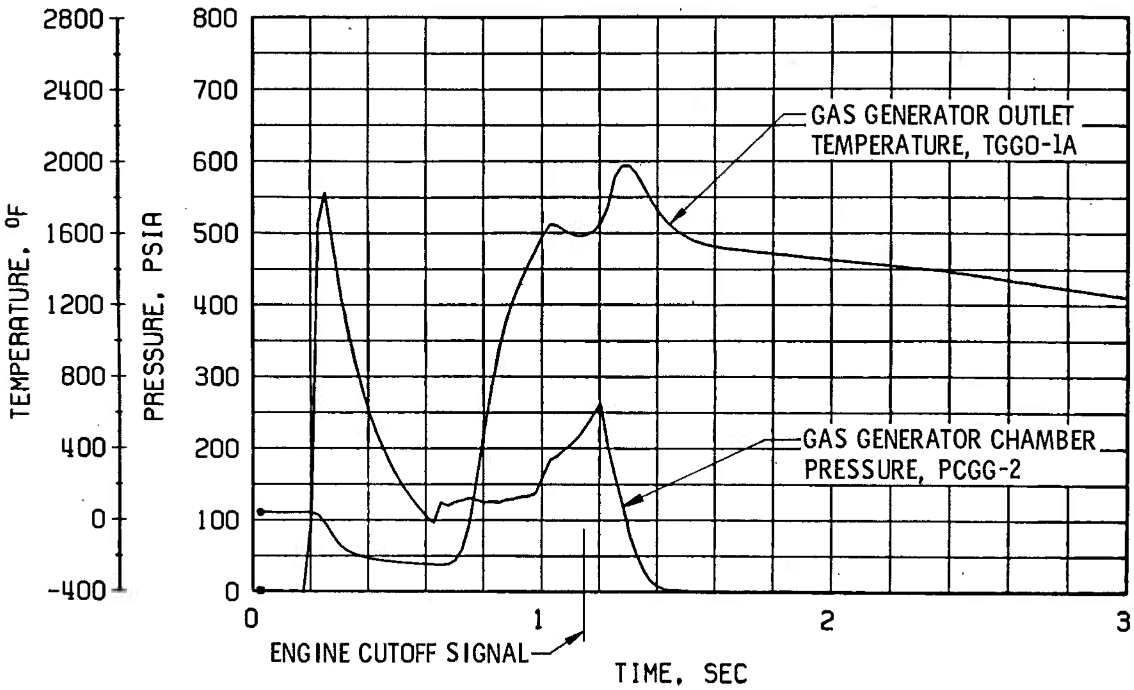


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 28 Engine Transient Operation, Firing 39E

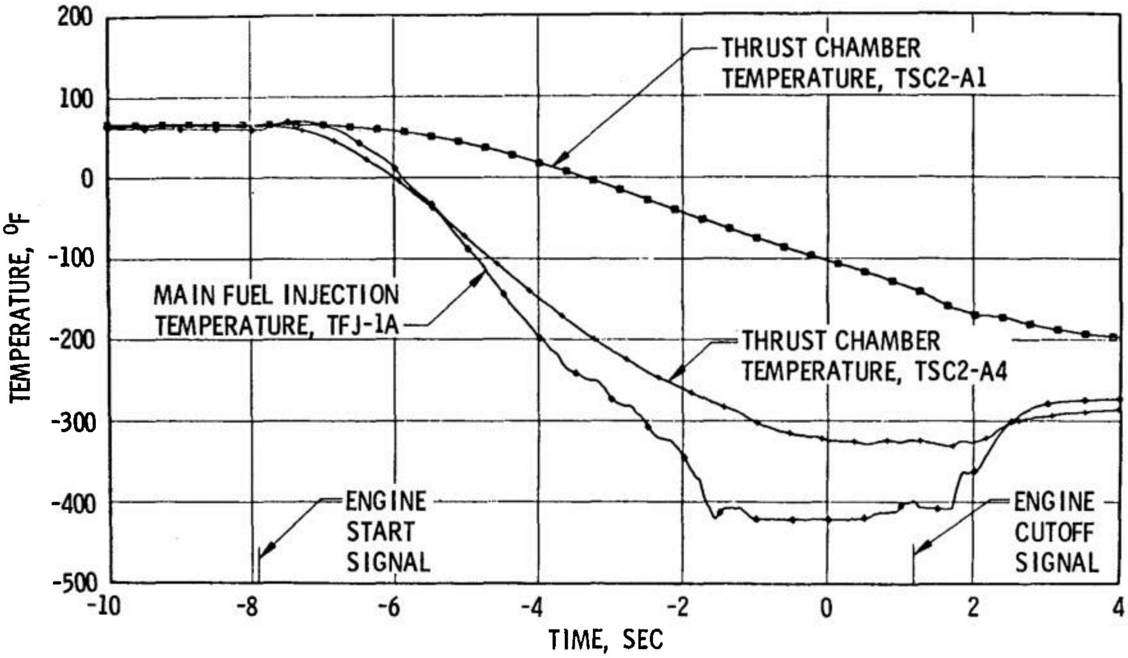


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown

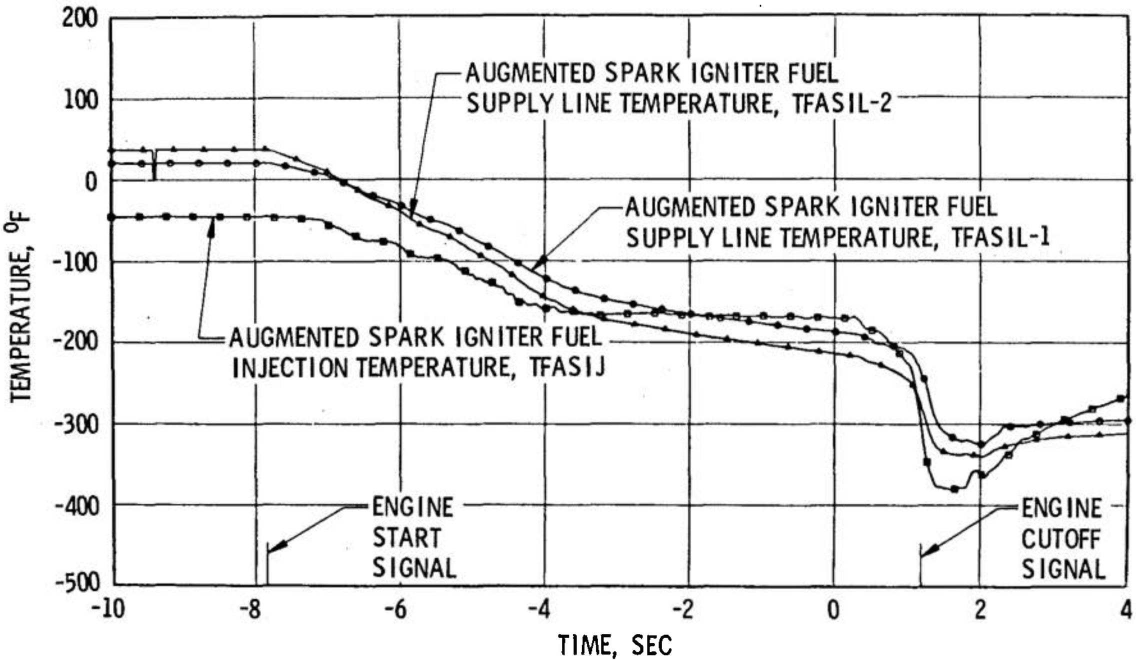


d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 28 Continued

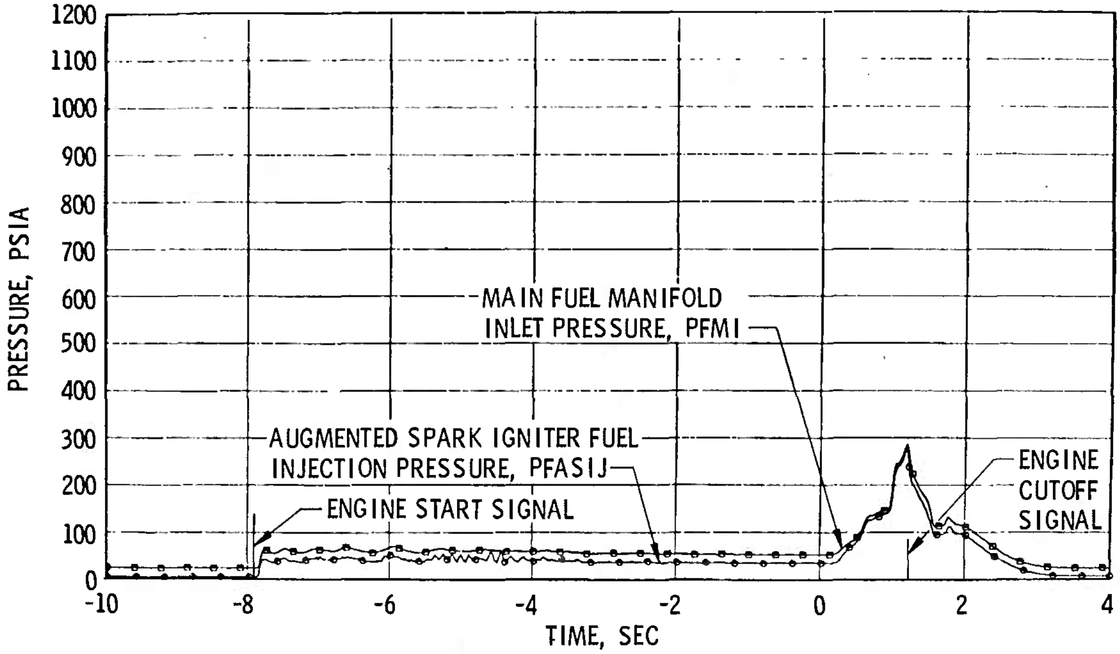


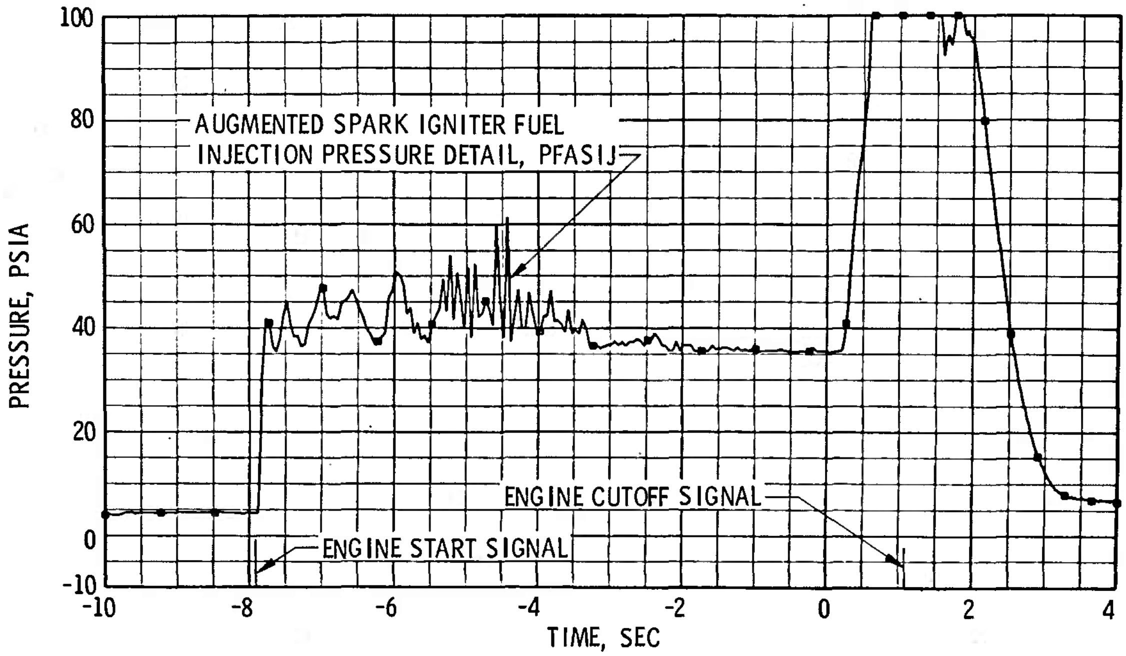
e. Thrust Chamber Temperature Transient



f. Augmented Spark Igniter Fuel Supply Line Temperature Transient

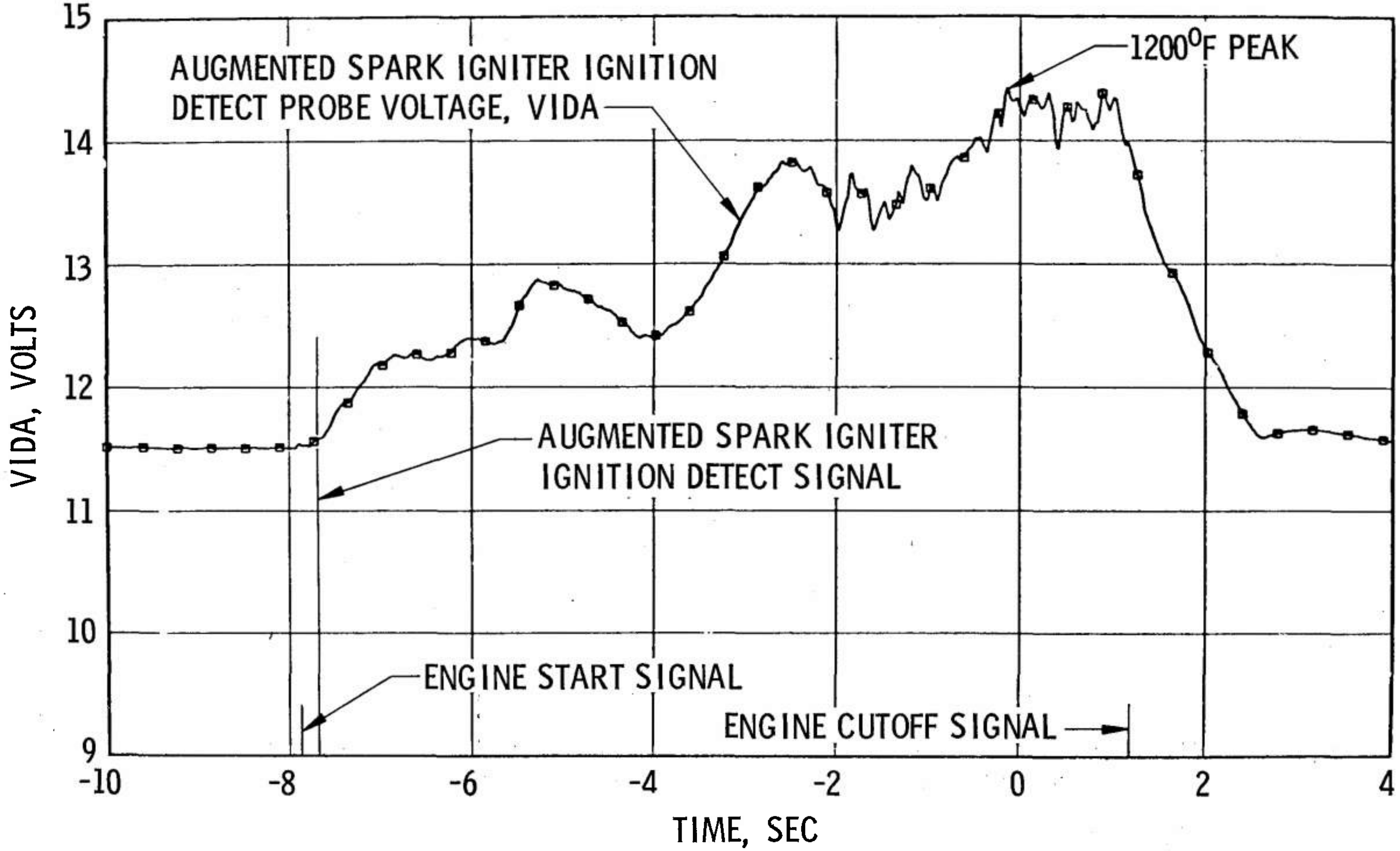
Fig. 28 Continued





g. Augmented Spark Igniter Fuel Supply Line Pressure Transient

Fig. 28 Continued



h. Augmented Spark Igniter Ignition Detect Probe Temperature Transient

Fig. 28 Concluded

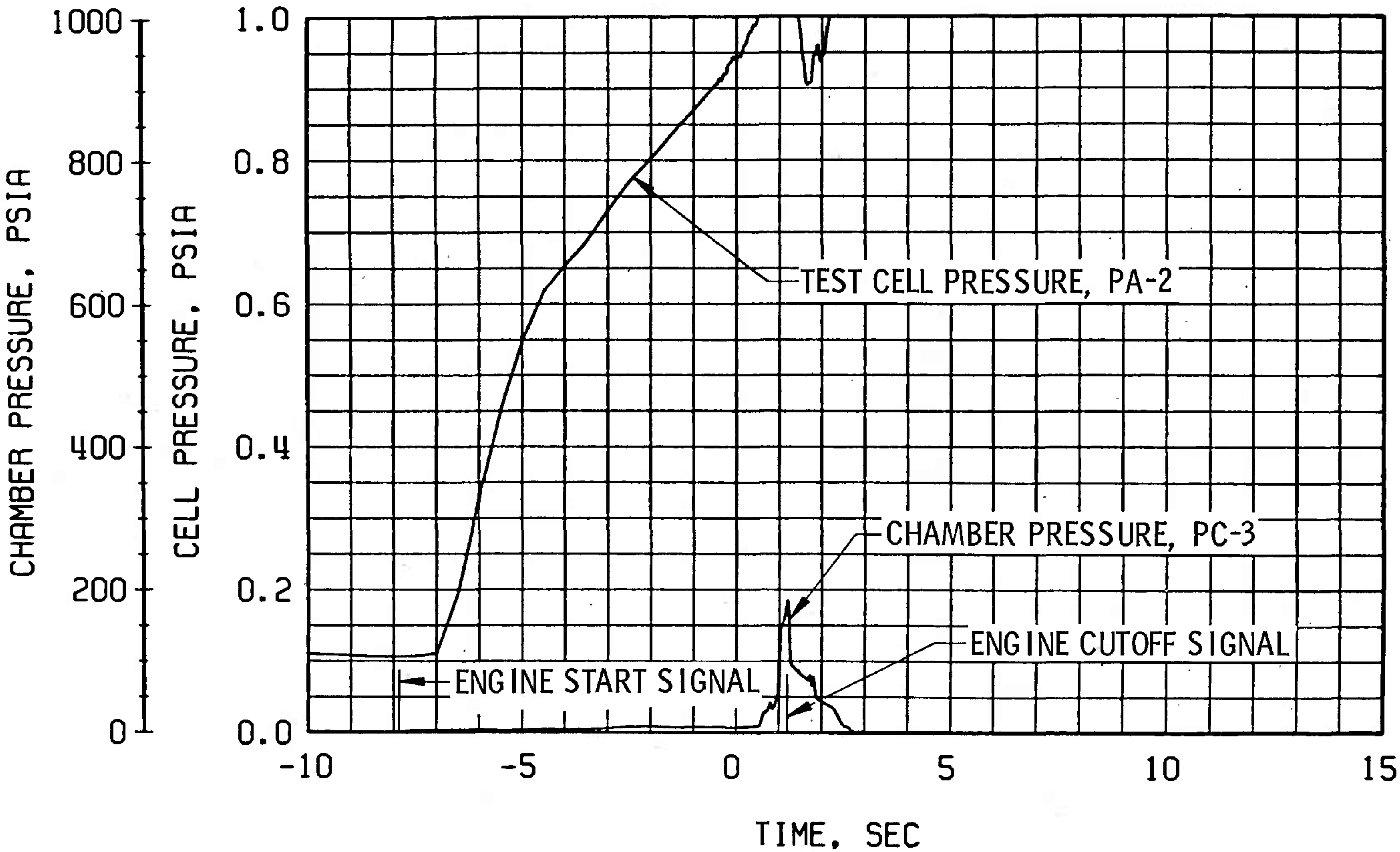


Fig. 29 Engine Ambient and Combustion Chamber Pressures, Firing 39E

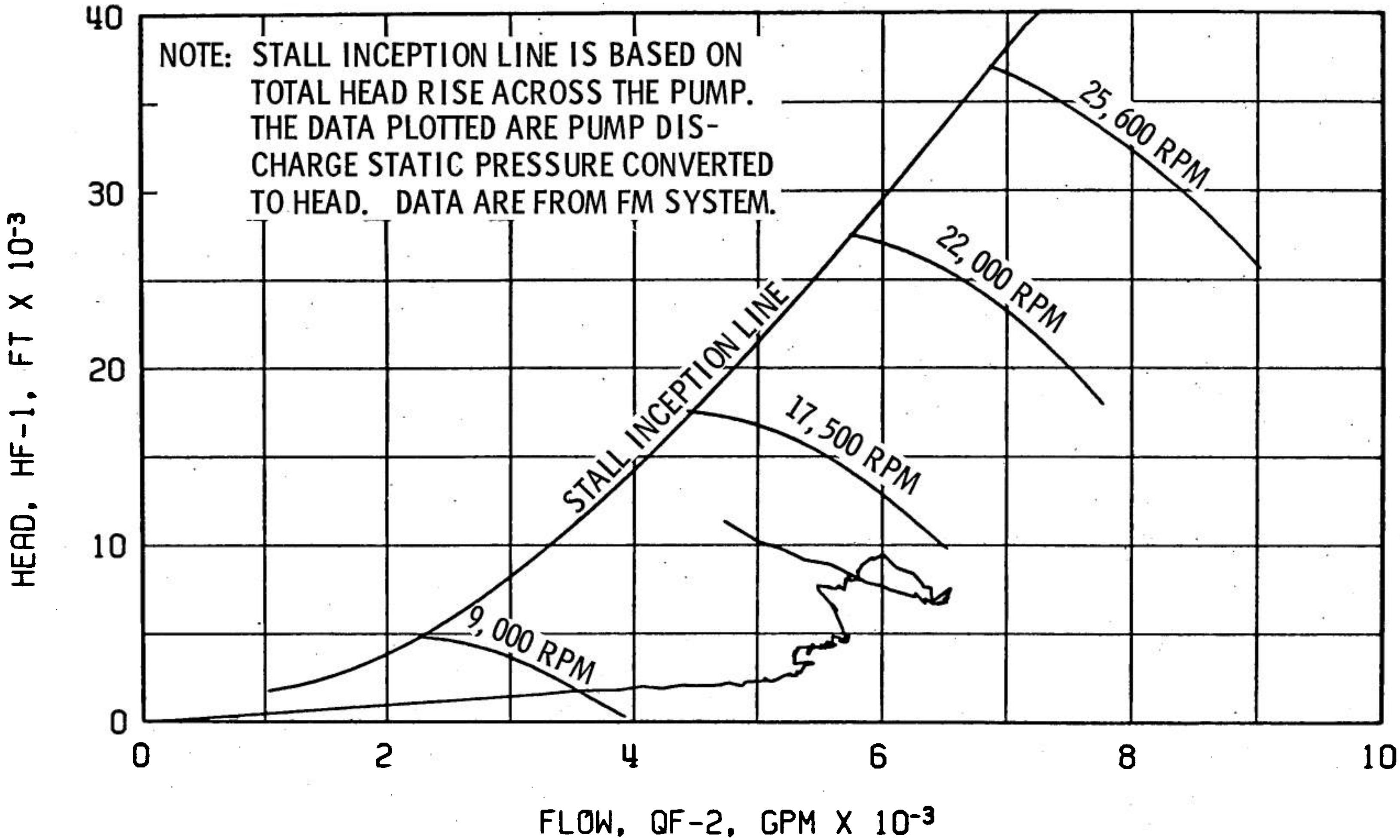
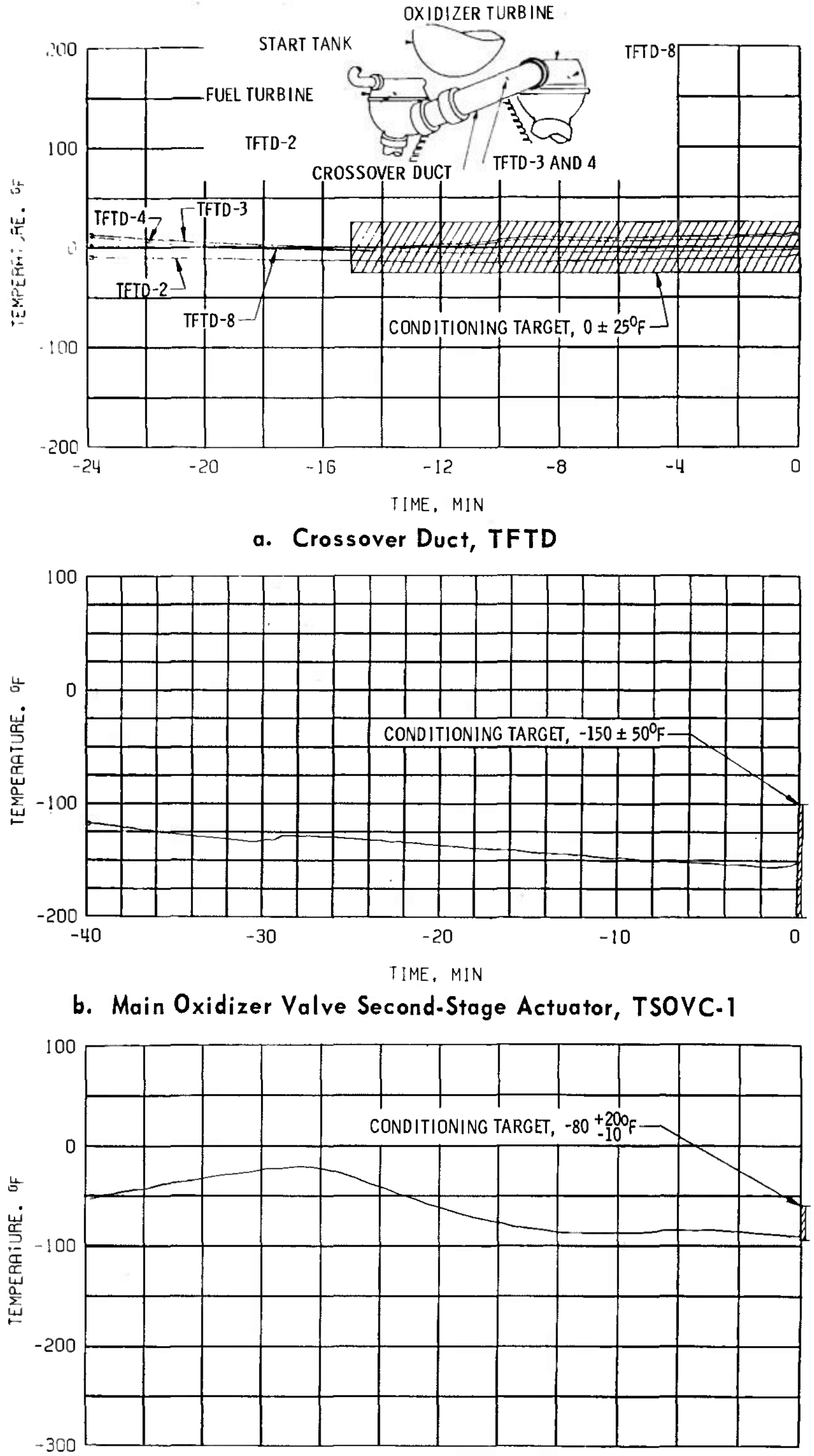


Fig. 30 Fuel Pump Start Transient Performance, Firing 39E

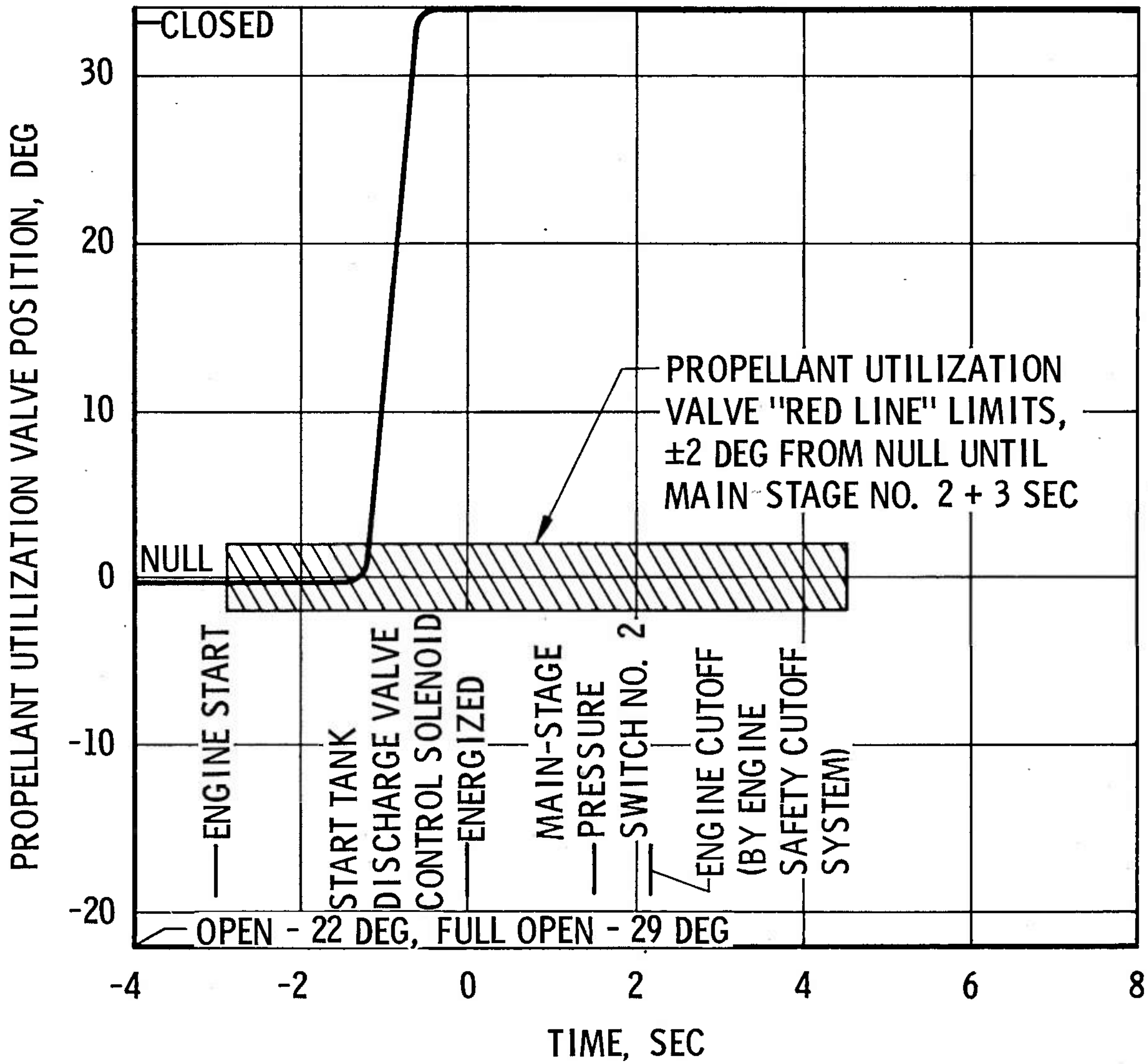


a. Crossover Duct, TFTD

b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

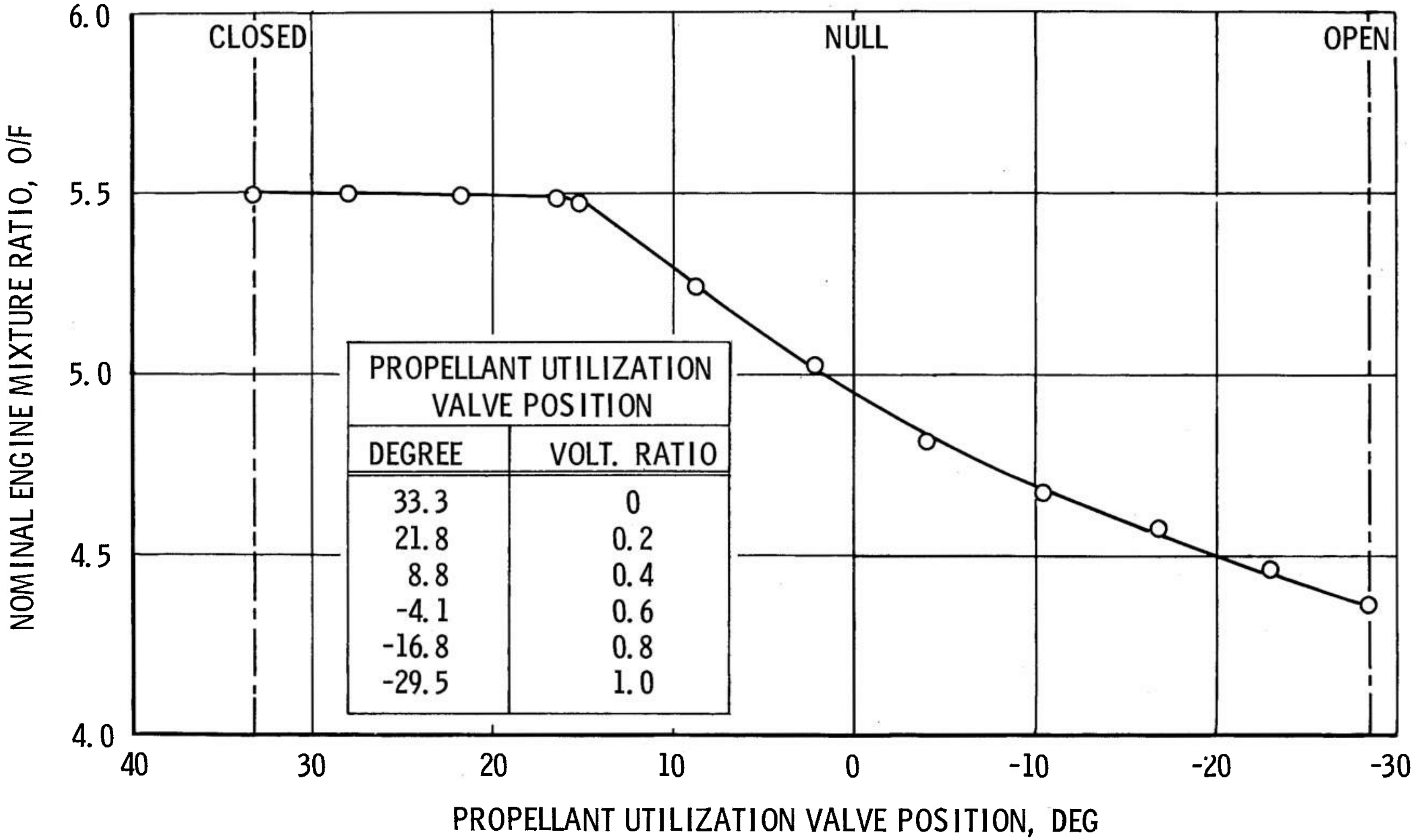
c. Thrust Chamber Throat, TTC-1P

Fig. 31 Thermal Conditioning History of Engine Components, Firing 40A



a. Propellant Utilization Valve Position History and "Red Line" Limits

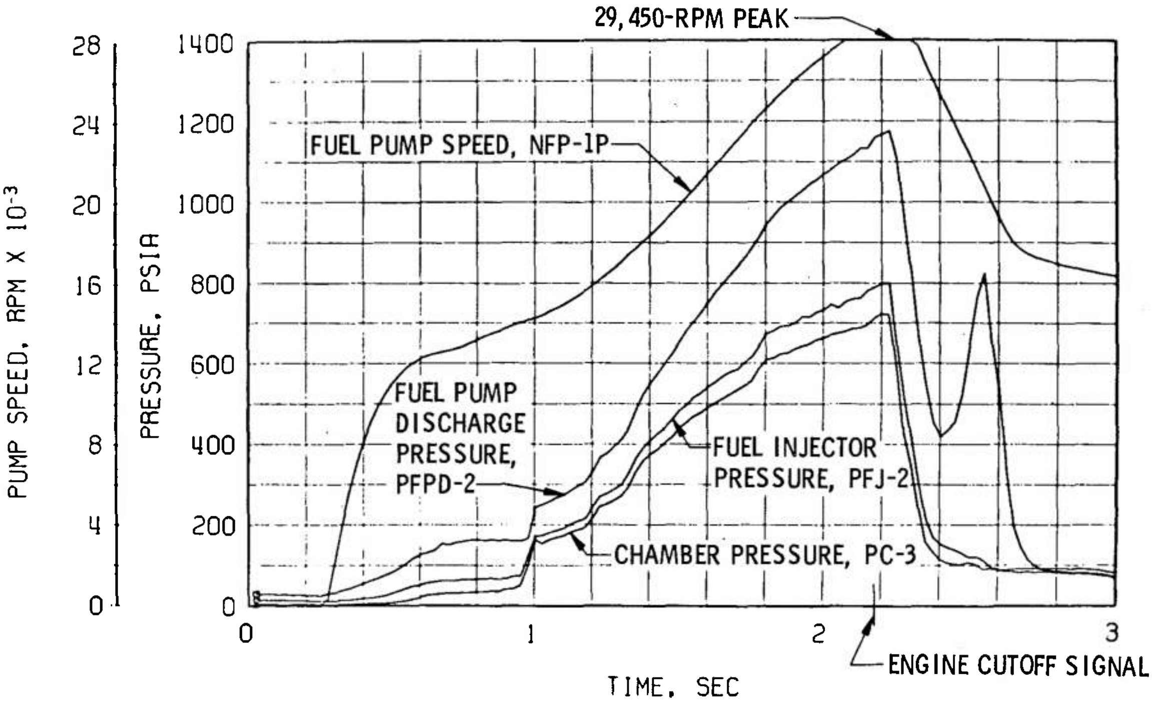
Fig. 32 Propellant Utilization Valve Excursion, Firing 40A



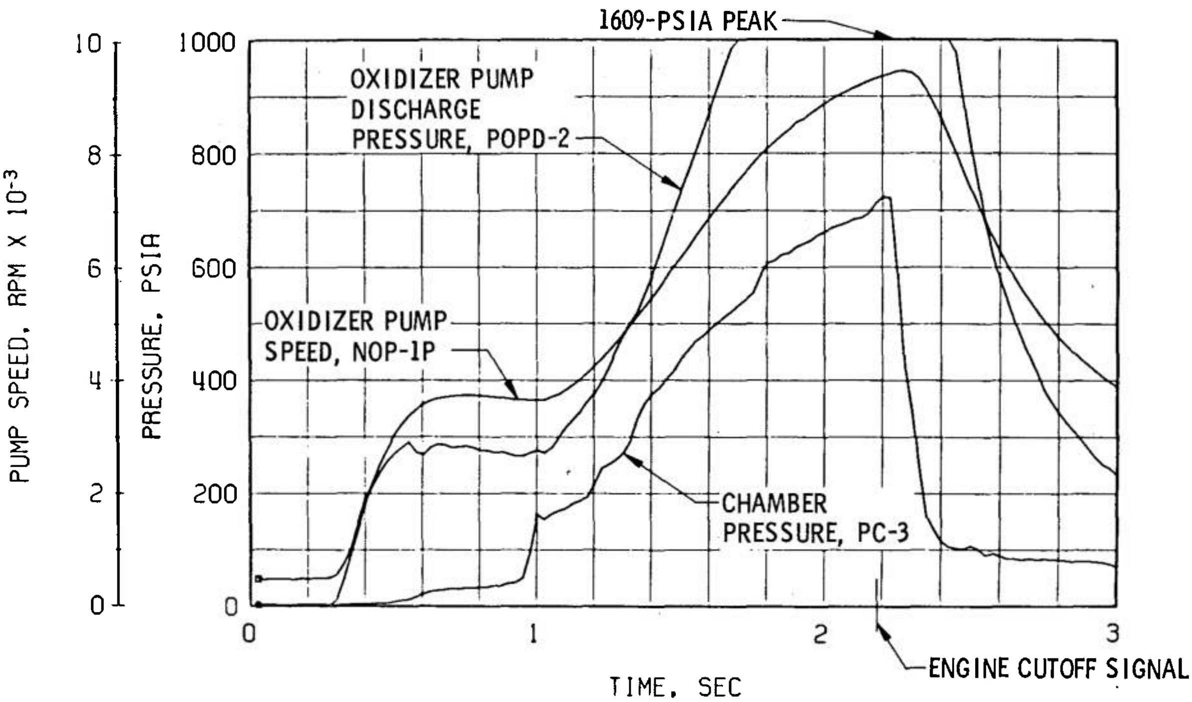
PROPELLANT UTILIZATION VALVE POSITION	
DEGREE	VOLT. RATIO
33.3	0
21.8	0.2
8.8	0.4
-4.1	0.6
-16.8	0.8
-29.5	1.0

b. Nominol Mixture Rotio of the J-2 Engine ond Propellont Utilization Valve Position

Fig. 32 Concluded

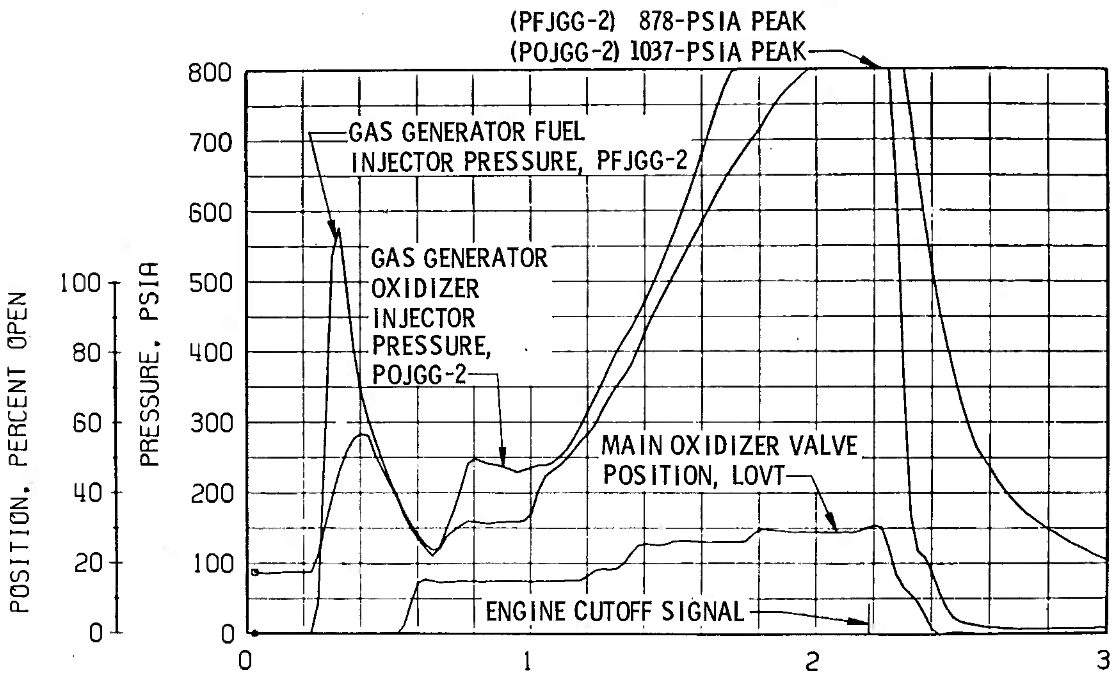


a. Thrust Chamber Fuel System

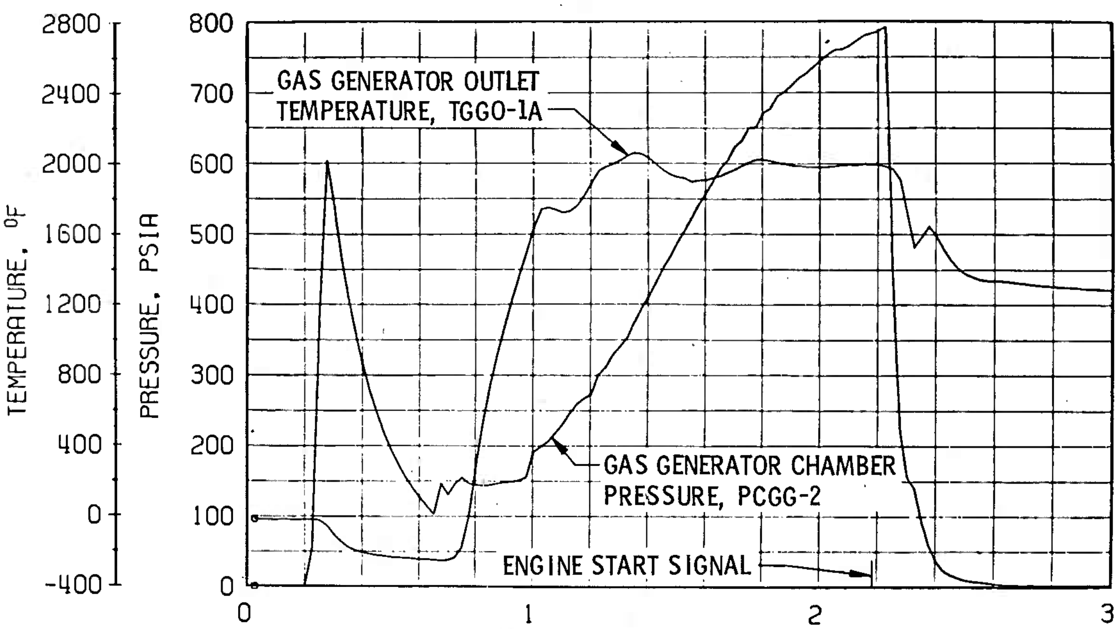


b. Thrust Chamber Oxidizer System

Fig. 33 Engine Transient Operation, Firing 40A

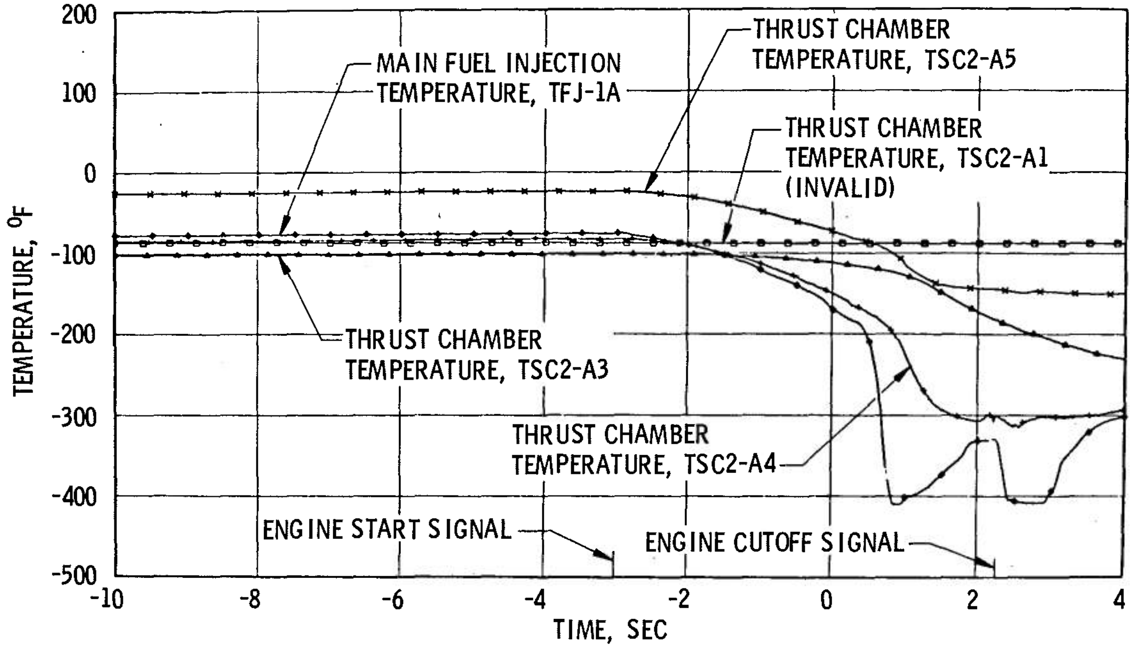


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position

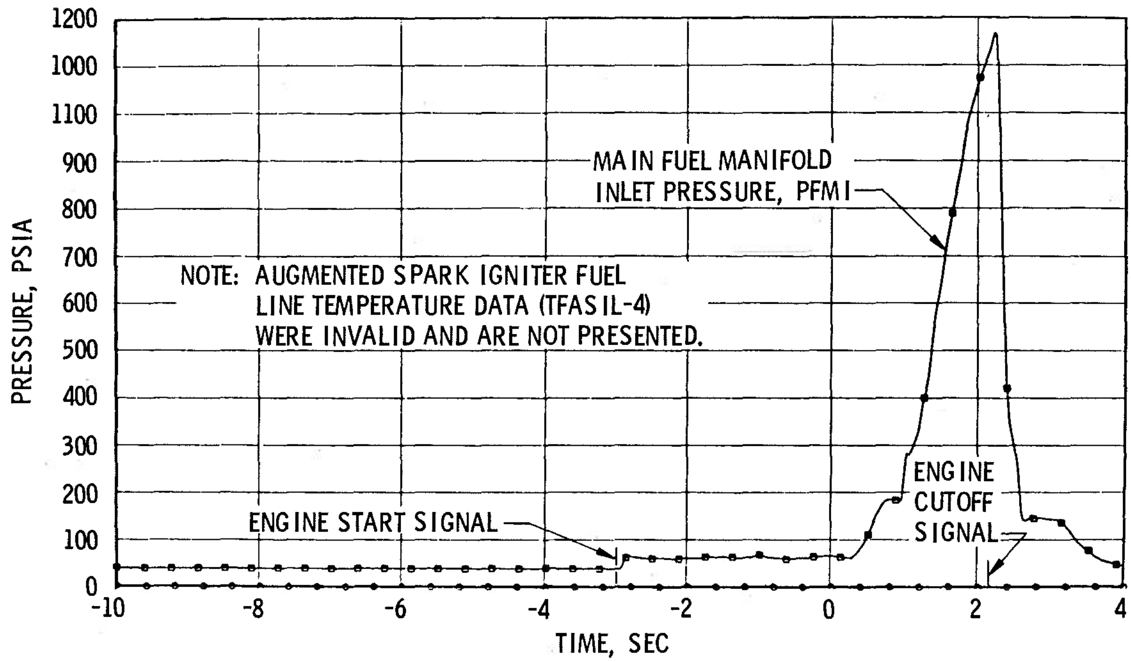


d. Gas Generator Chamber Pressure and Temperature

Fig. 33 Continued

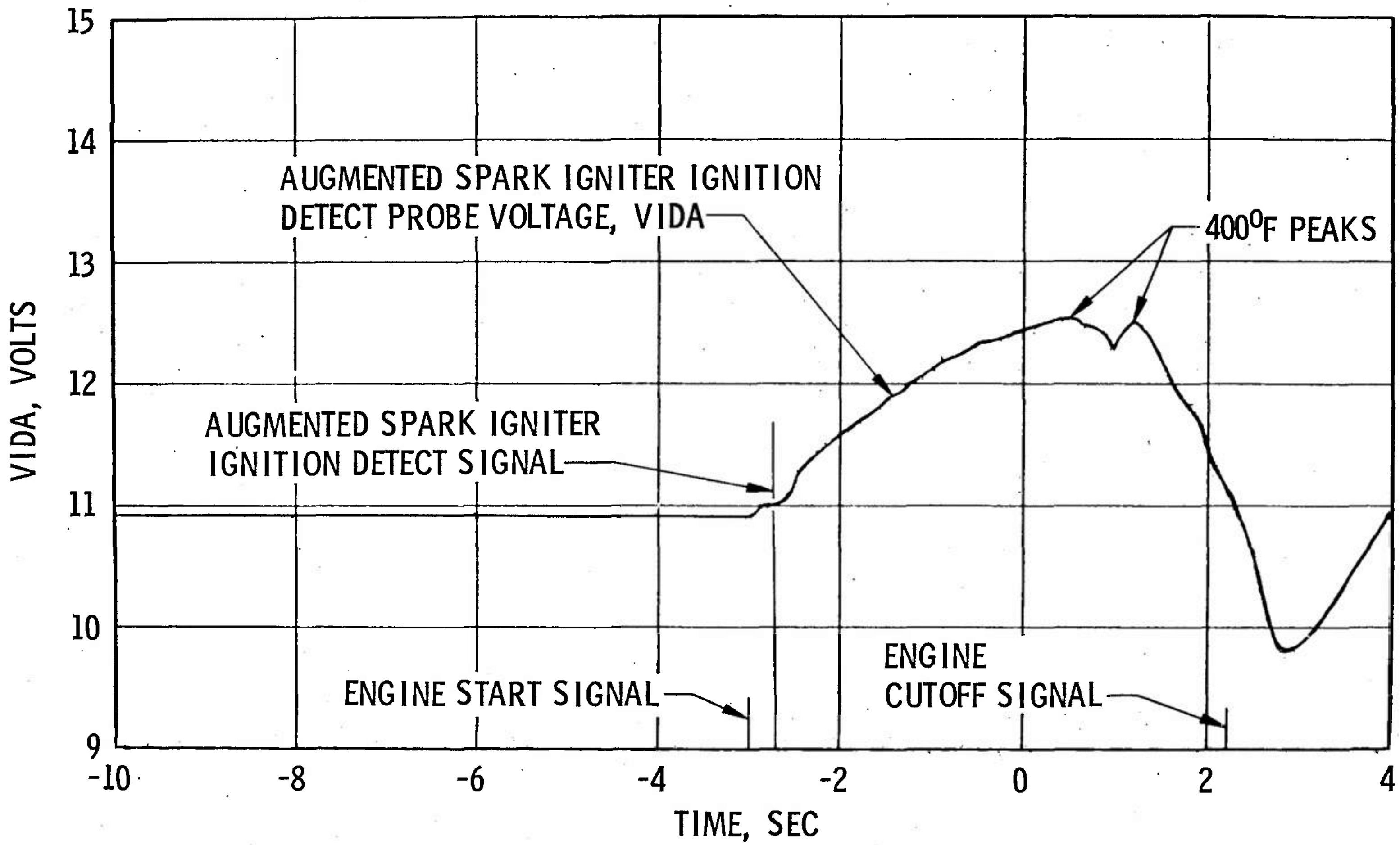


e. Thrust Chamber Temperature Transient



f. Augmented Spark Igniter Fuel Supply Line Pressure Transient

Fig. 33 Continued



g. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start and Shutdown

Fig. 33 Concluded

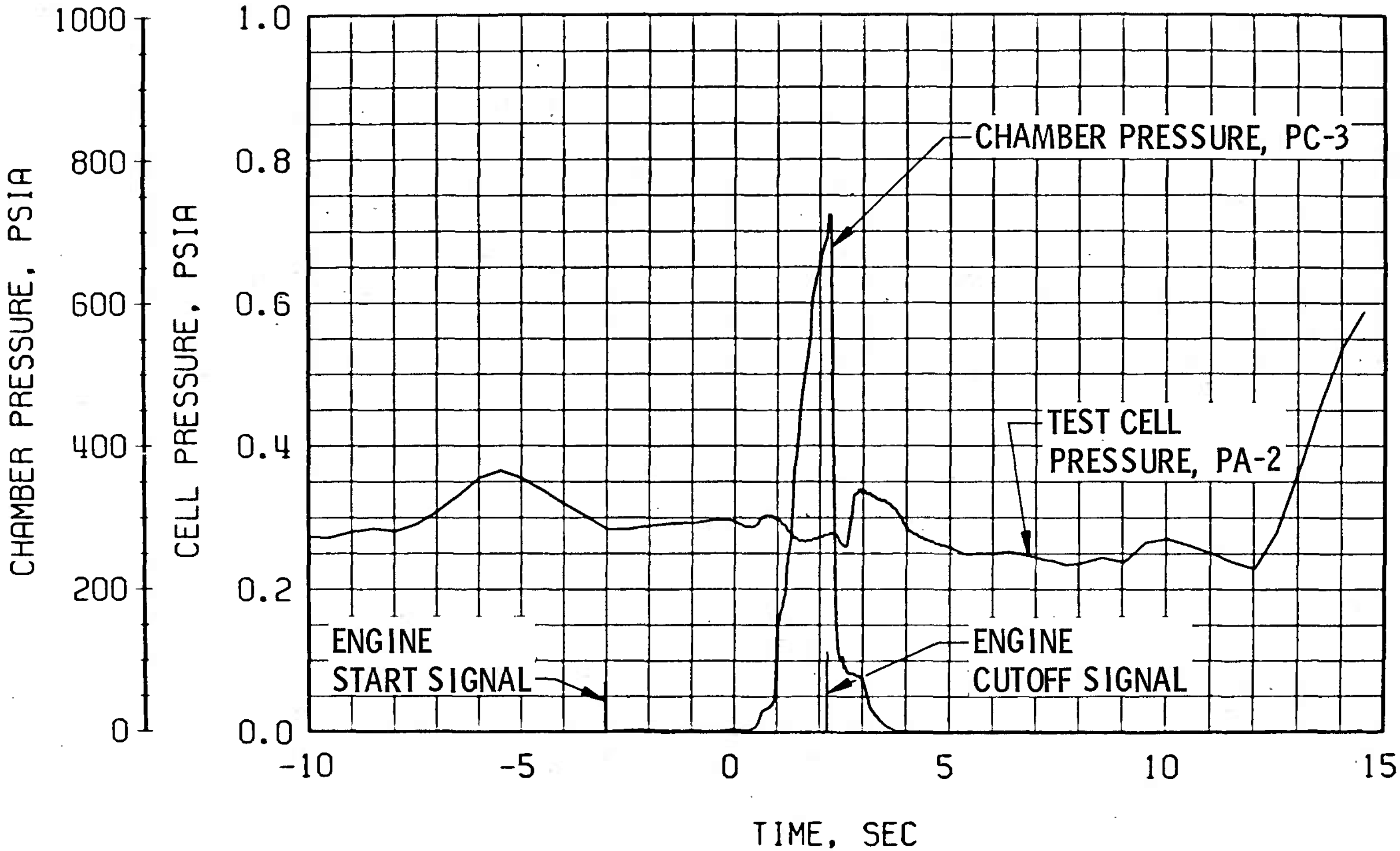


Fig. 34 Engine Ambient and Combustion Chamber Pressures, Firing 40A

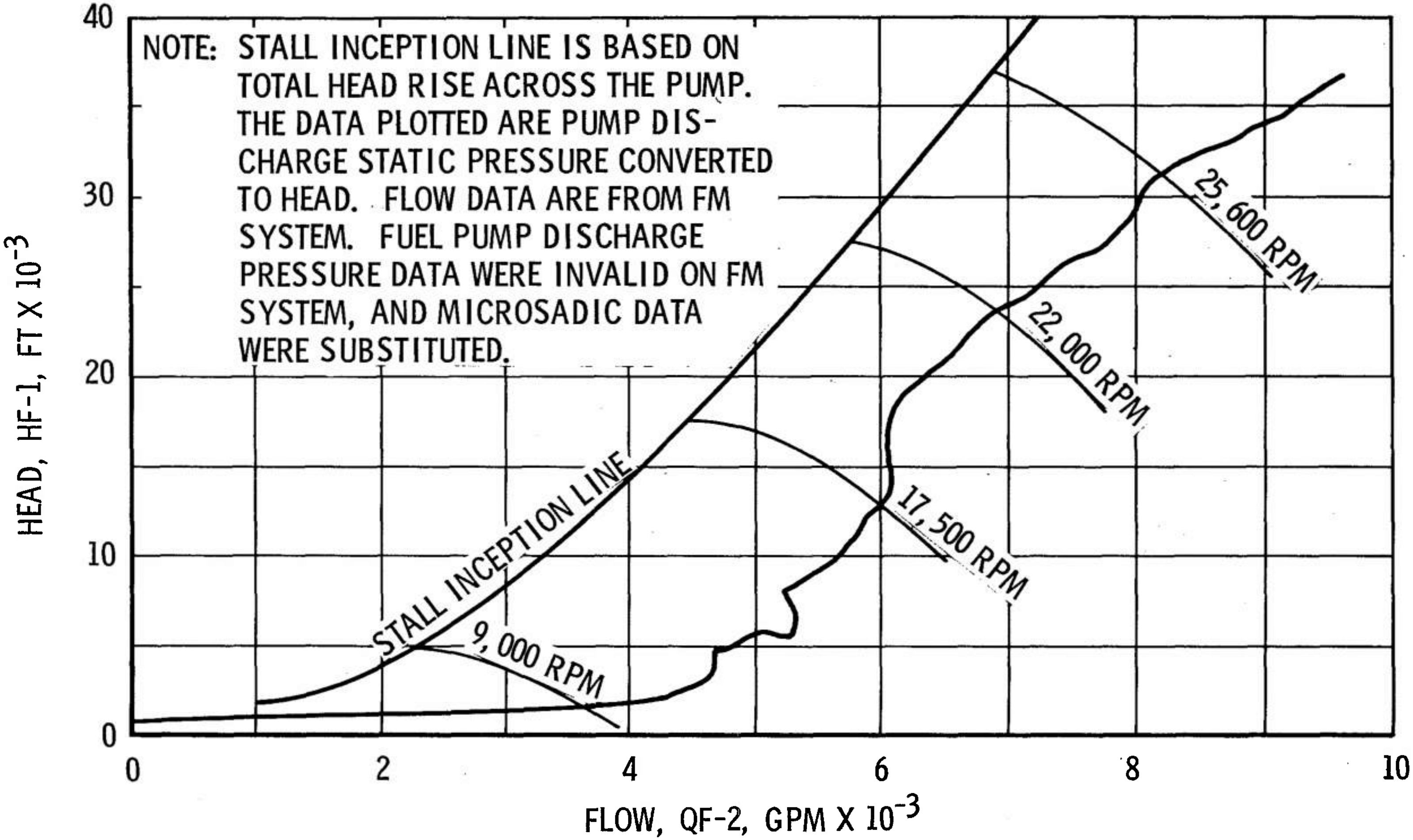
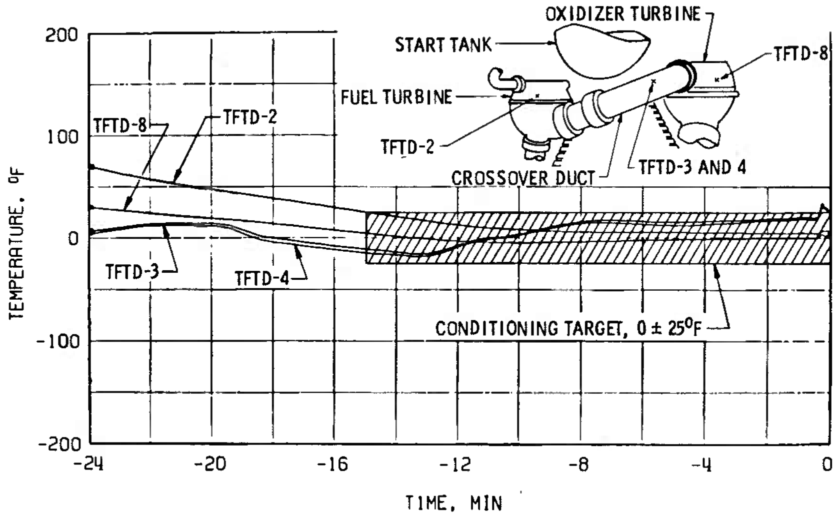
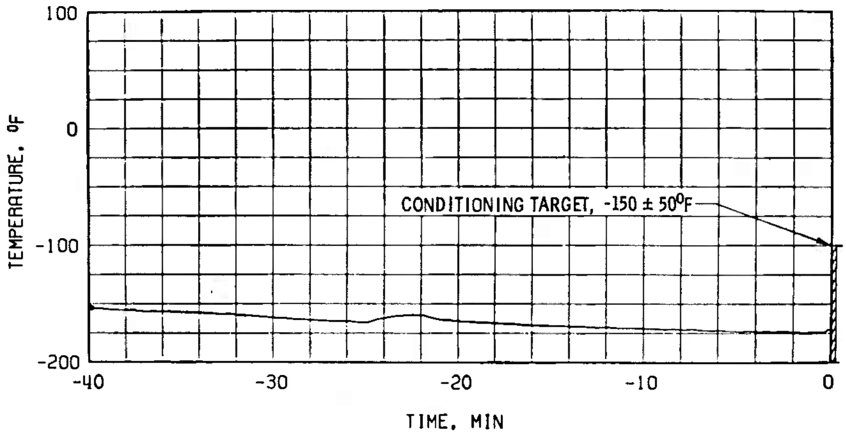


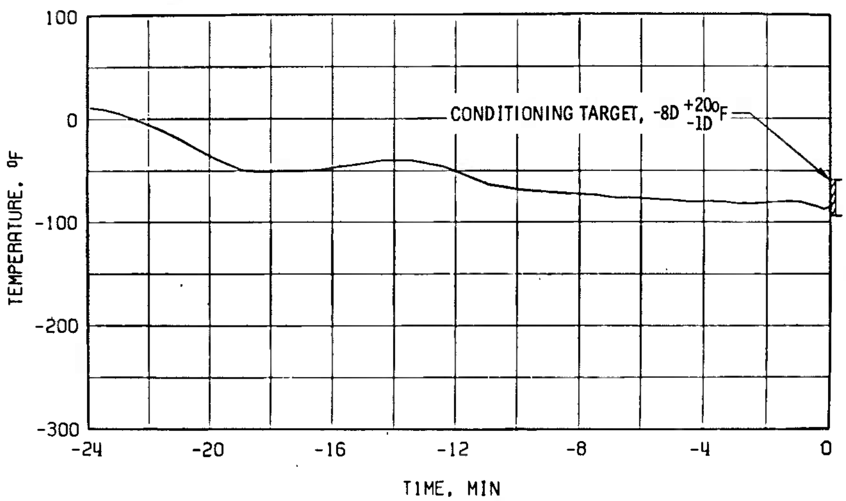
Fig. 35 Fuel Pump Start Transient Performance, Firing 40A



a. Crossover Duct, TFTD

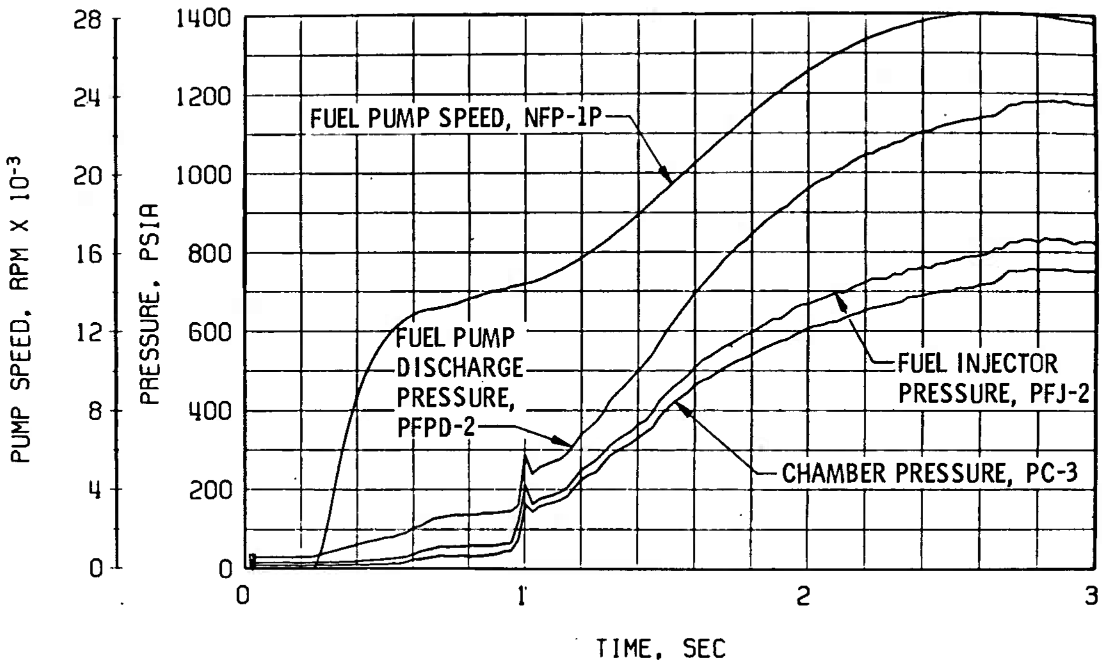


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

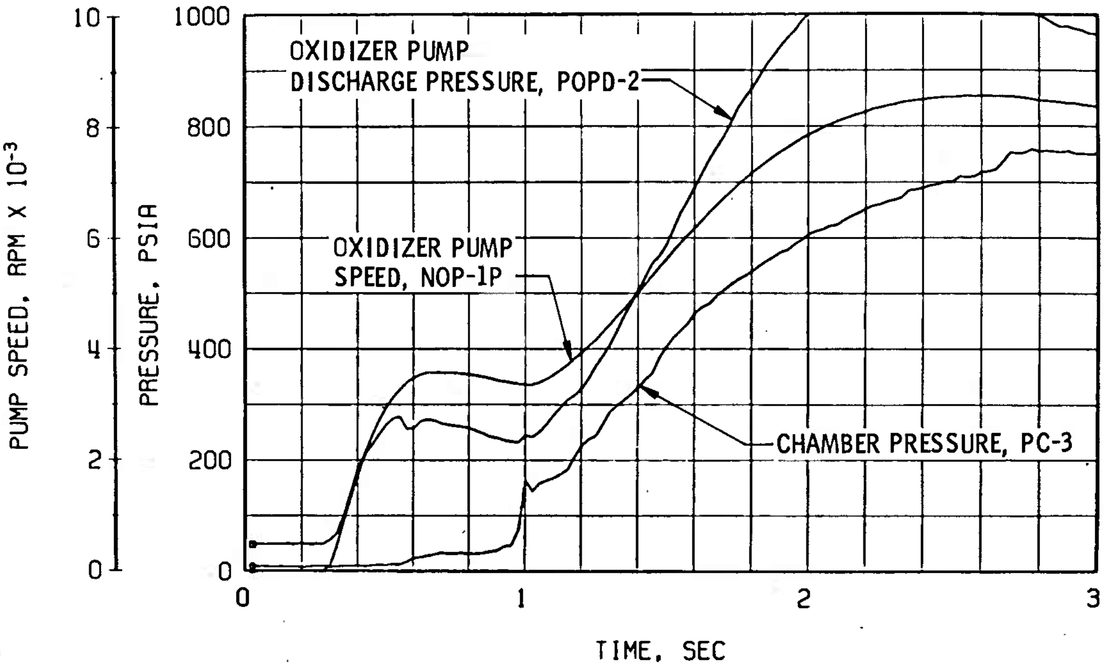


c. Thrust Chamber Throat, TTC-1P

Fig. 36 Thermal Conditioning History of Engine Components, Firing 40AA

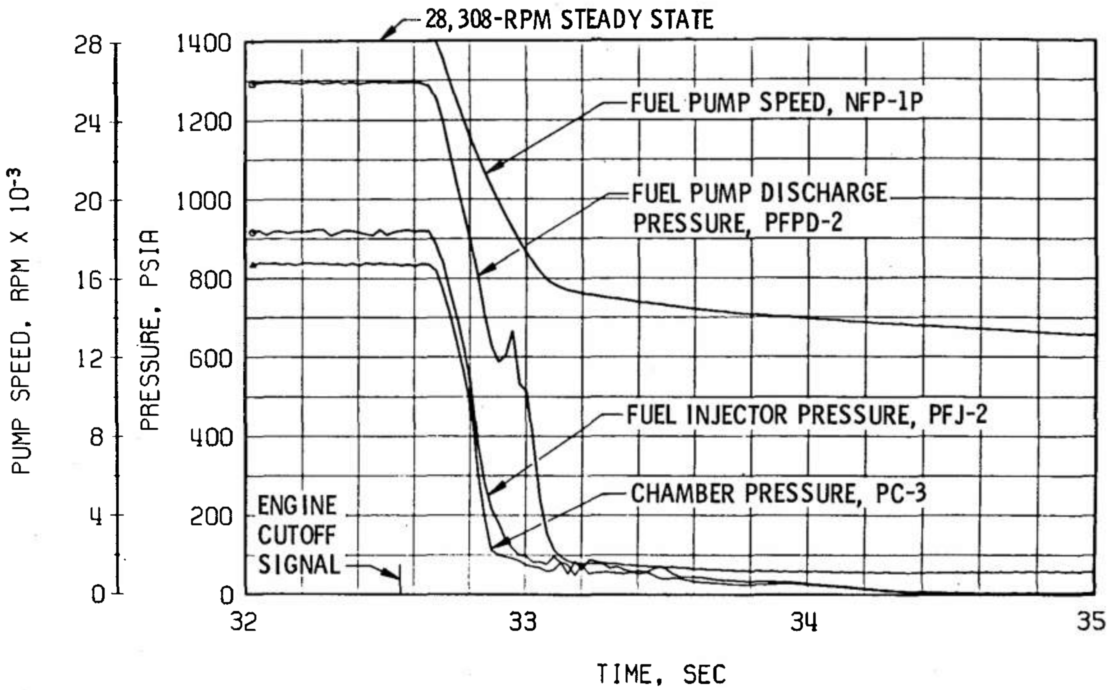


a. Thrust Chamber Fuel System, Start

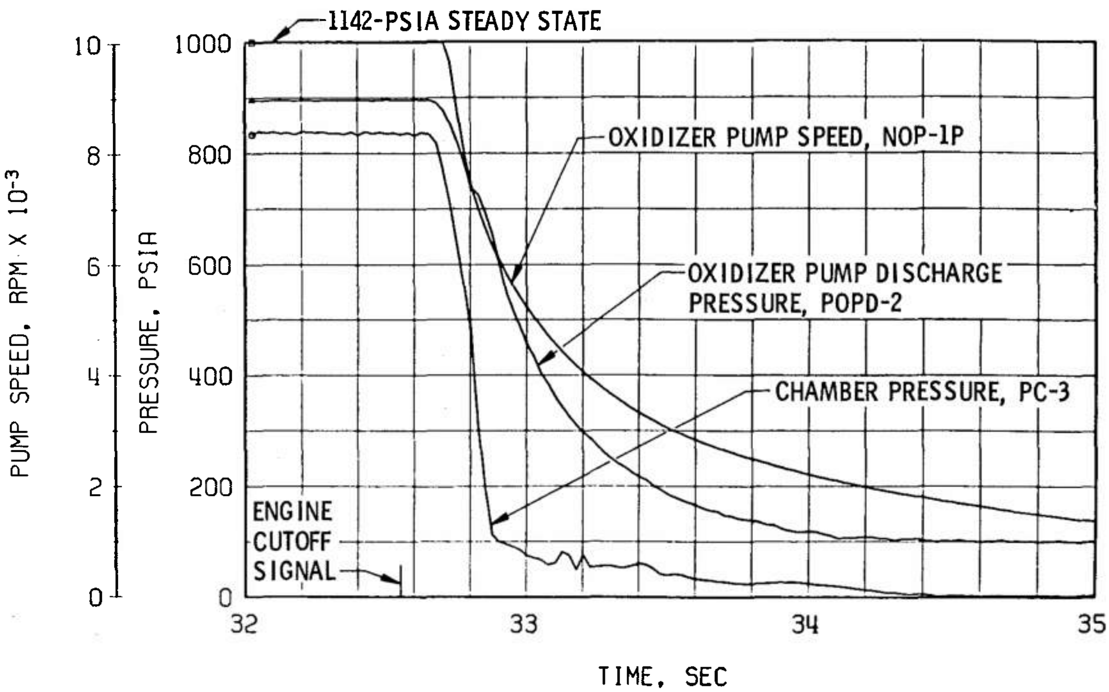


b. Thrust Chamber Oxidizer System, Start

Fig. 37 Engine Transient Operation, Firing 40AA

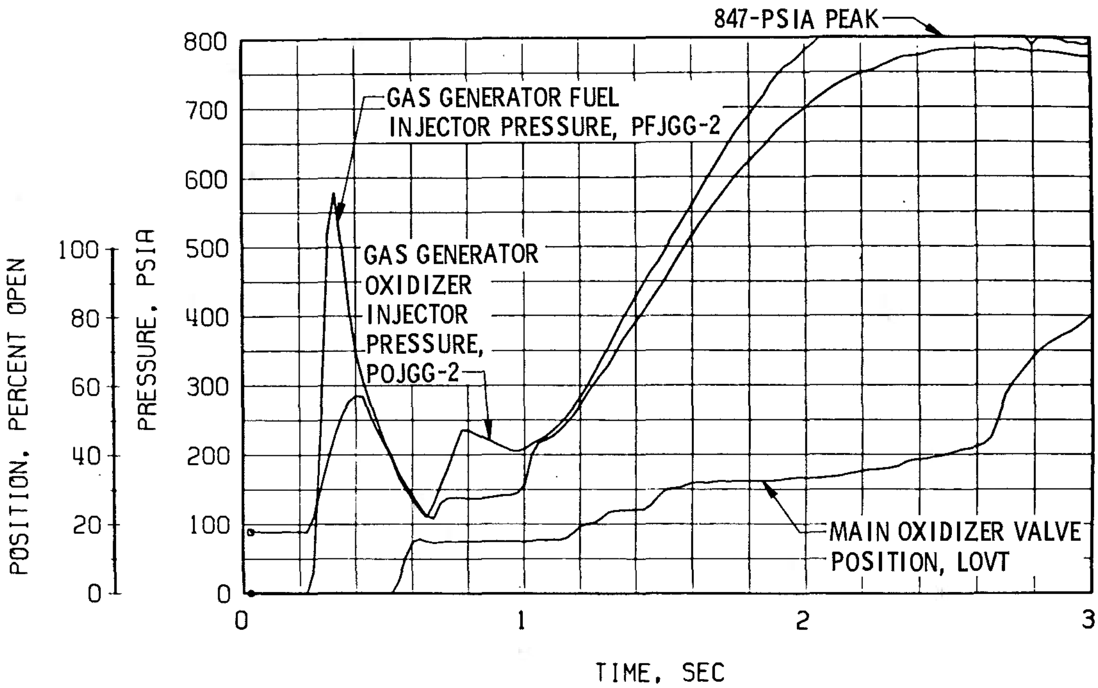


c. Thrust Chamber Fuel System, Shutdown

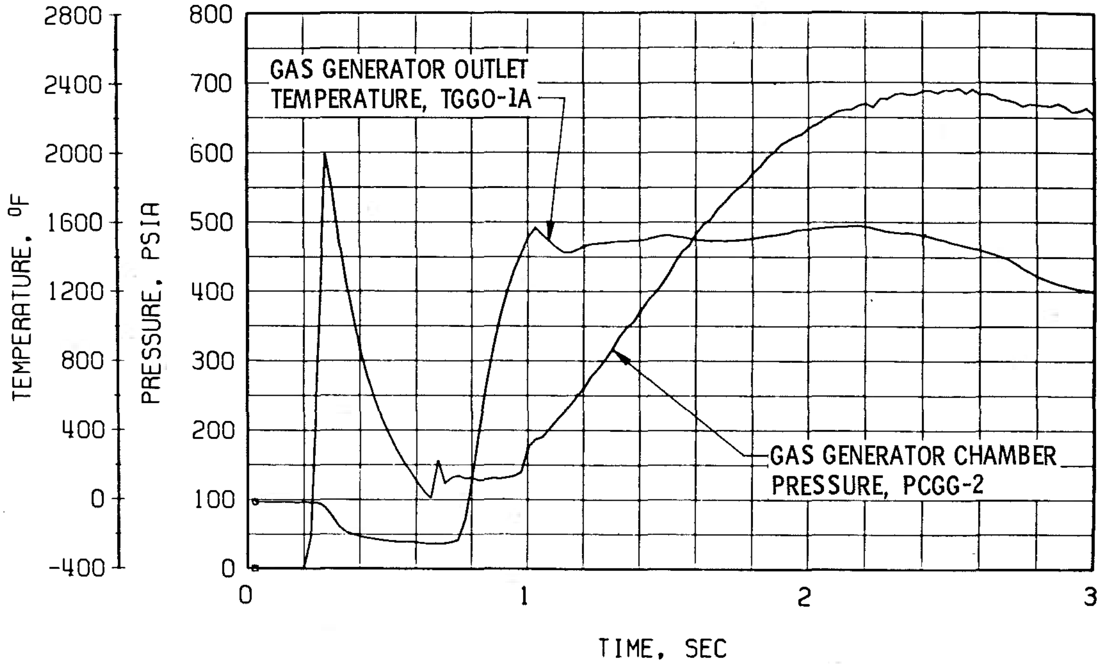


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 37 Continued

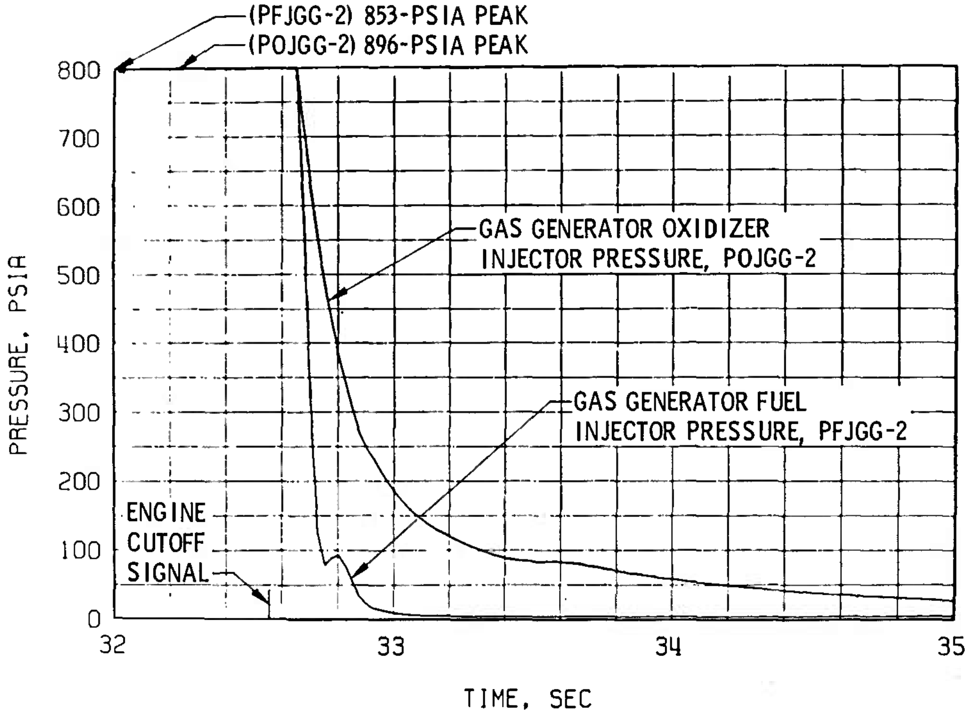


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

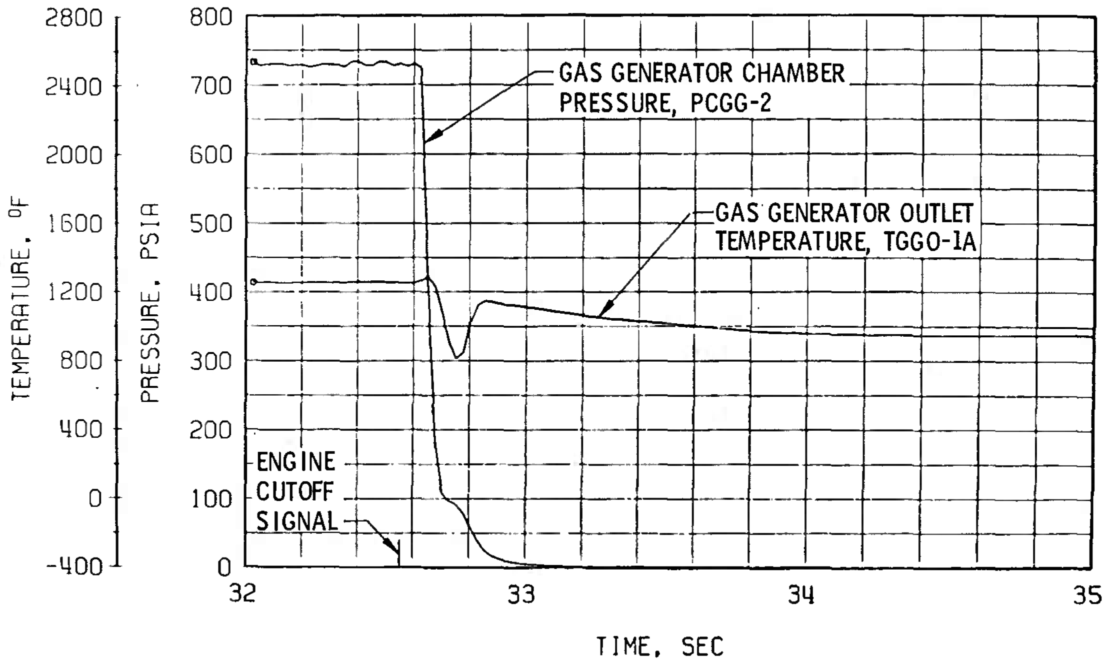


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 37 Continued

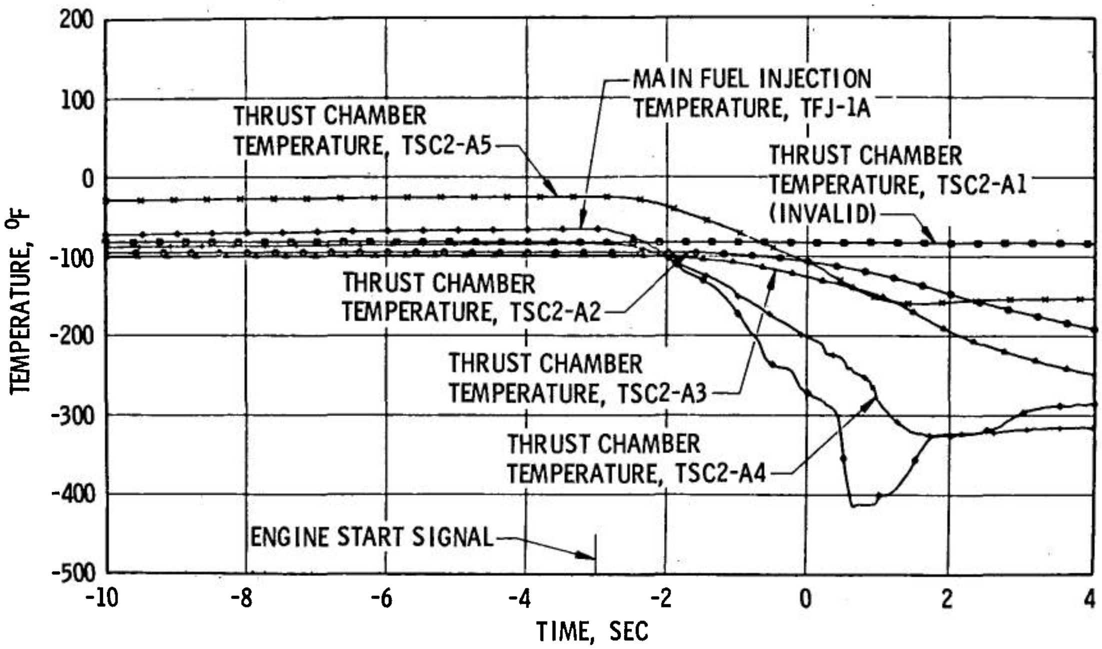


g. **Gas Generator Injector Pressures, Shutdown**

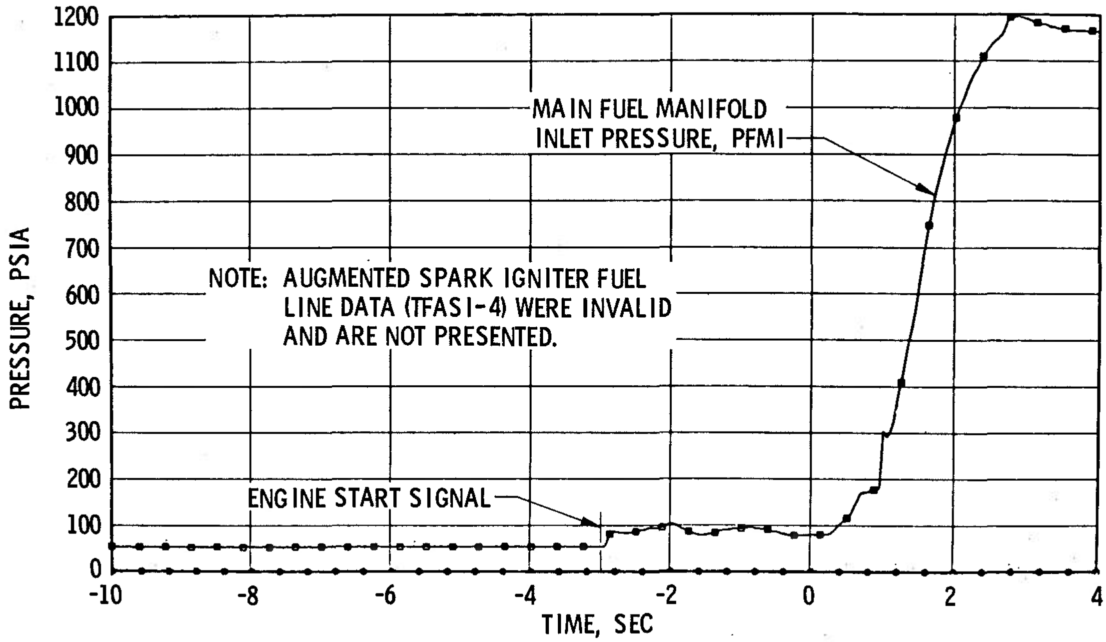


h. **Gas Generator Chamber Pressure and Temperature, Shutdown**

Fig. 37 Continued

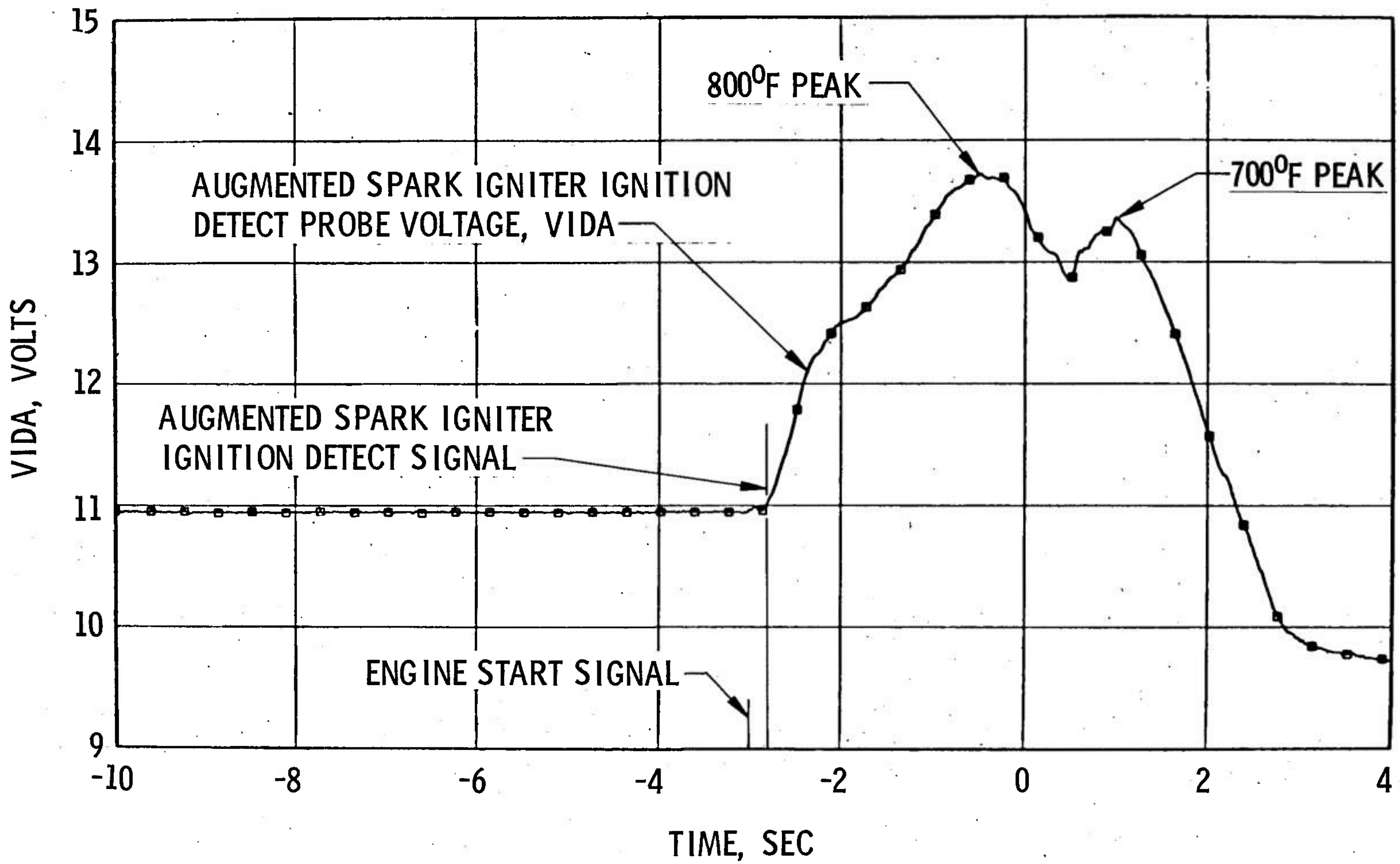


i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

Fig. 37 Continued



k. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 37 Concluded

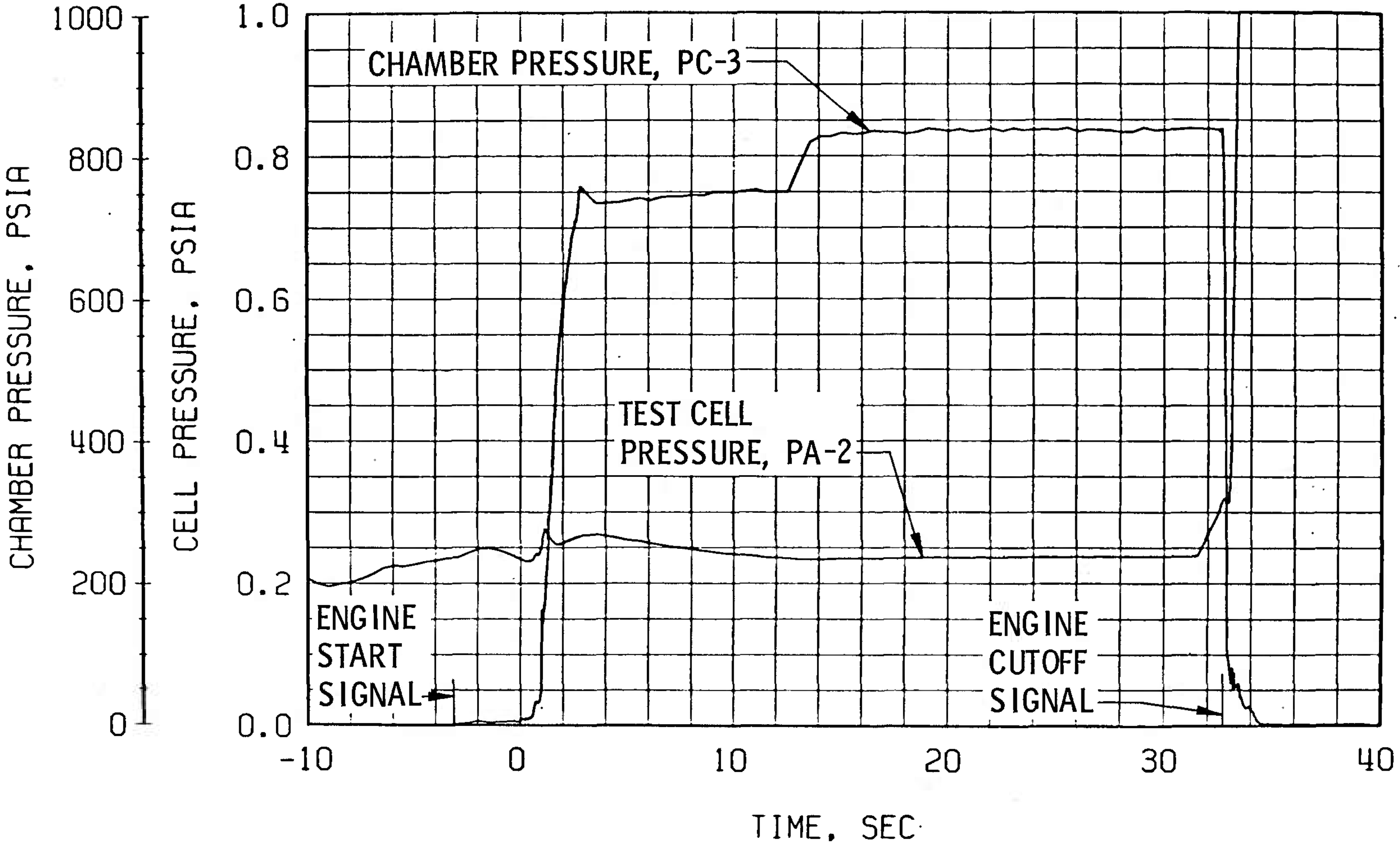


Fig. 38 Engine Ambient and Combustion Chamber Pressures, Firing 40AA

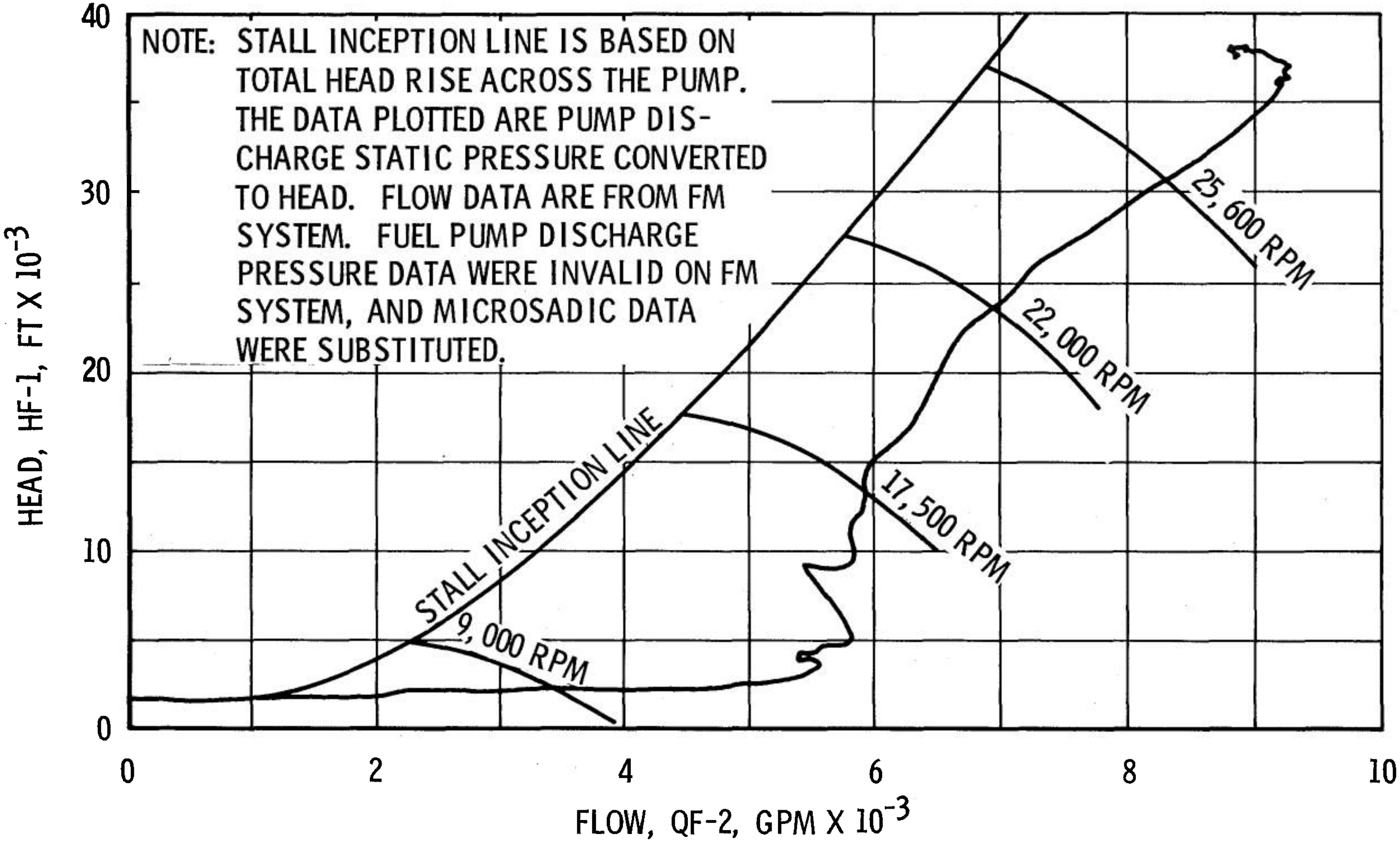
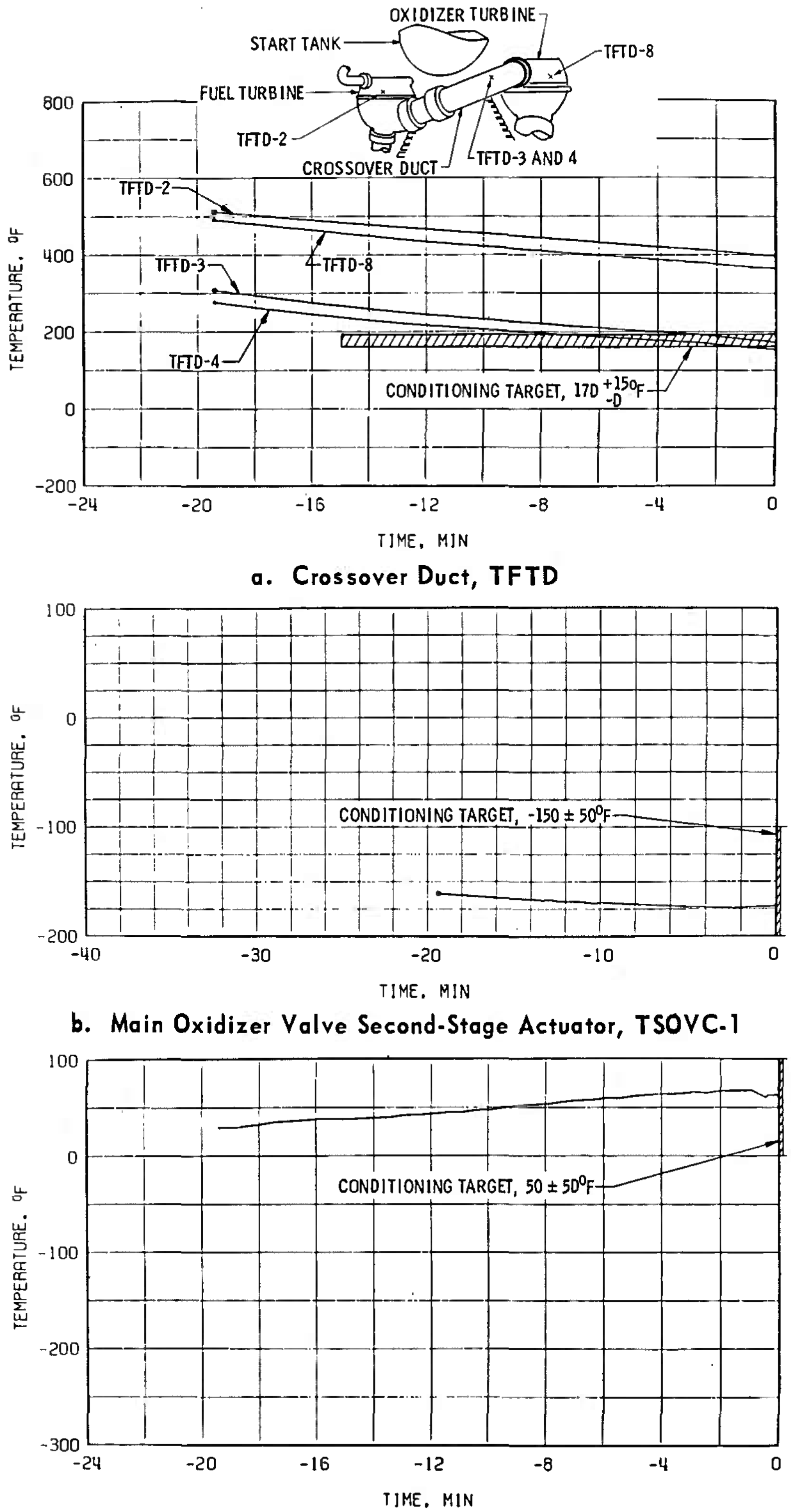


Fig. 39 Fuel Pump Start Transient Performance, Firing 40AA

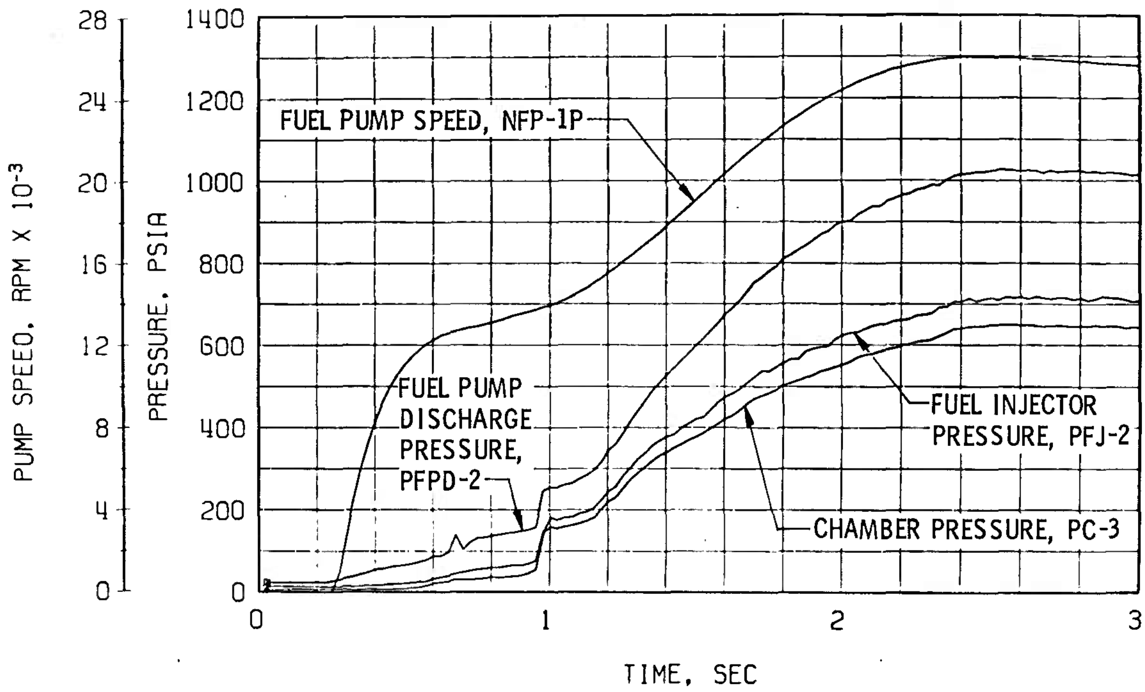


a. Crossover Duct, TFTD

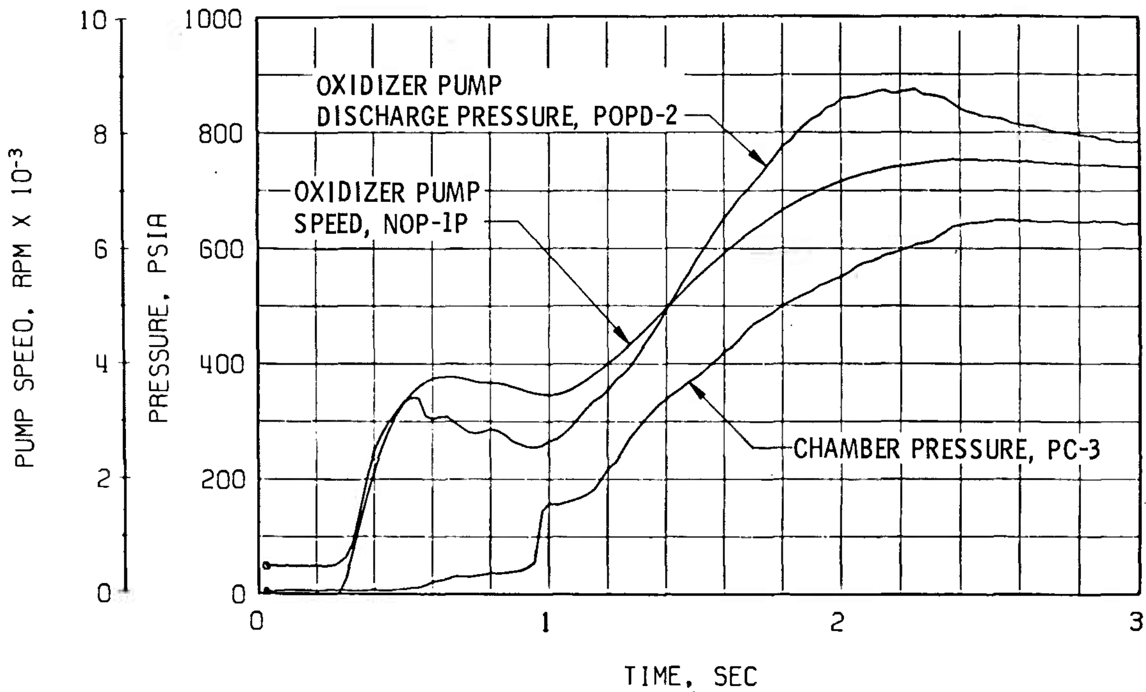
b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

c. Thrust Chamber Throat, TTC-1P

Fig. 40 Thermal Conditioning History of Engine Components, Firing 40B

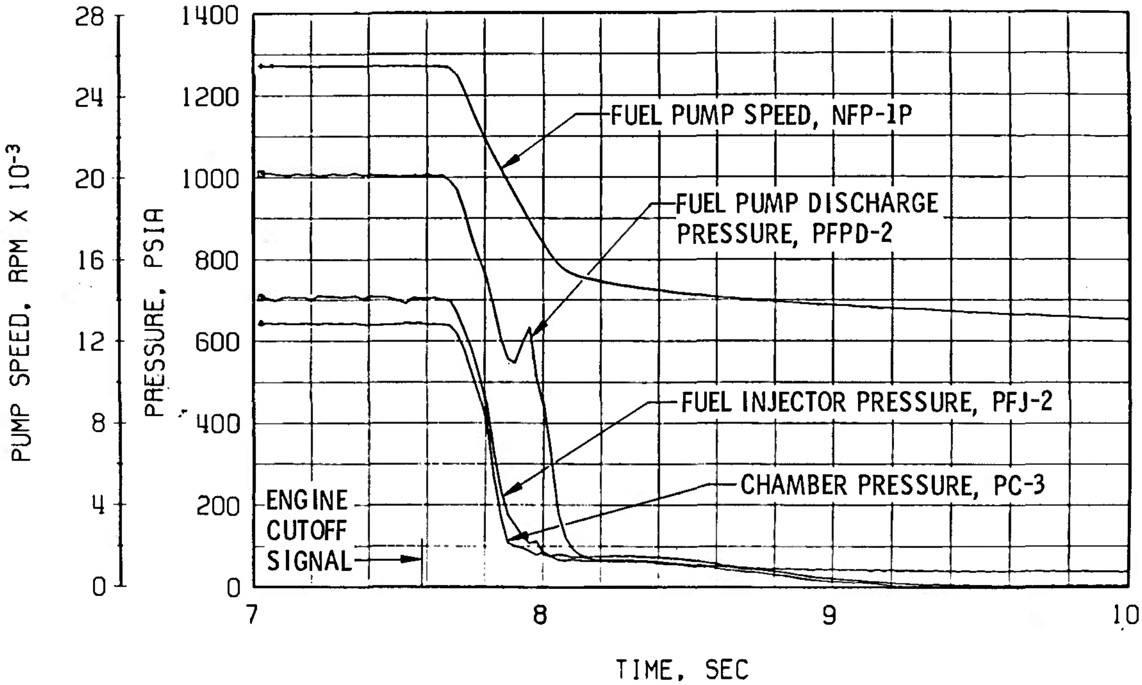


a. Thrust Chamber Fuel System, Start

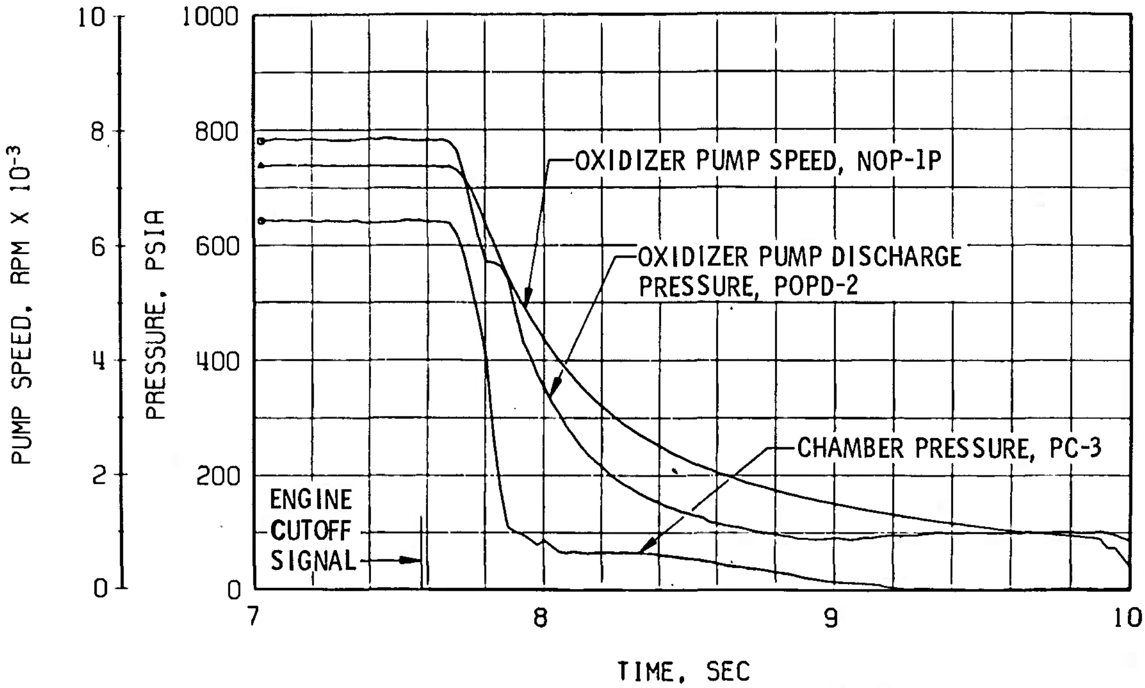


b. Thrust Chamber Oxidizer System, Start

Fig. 41 Engine Transient Operation, Firing 40B

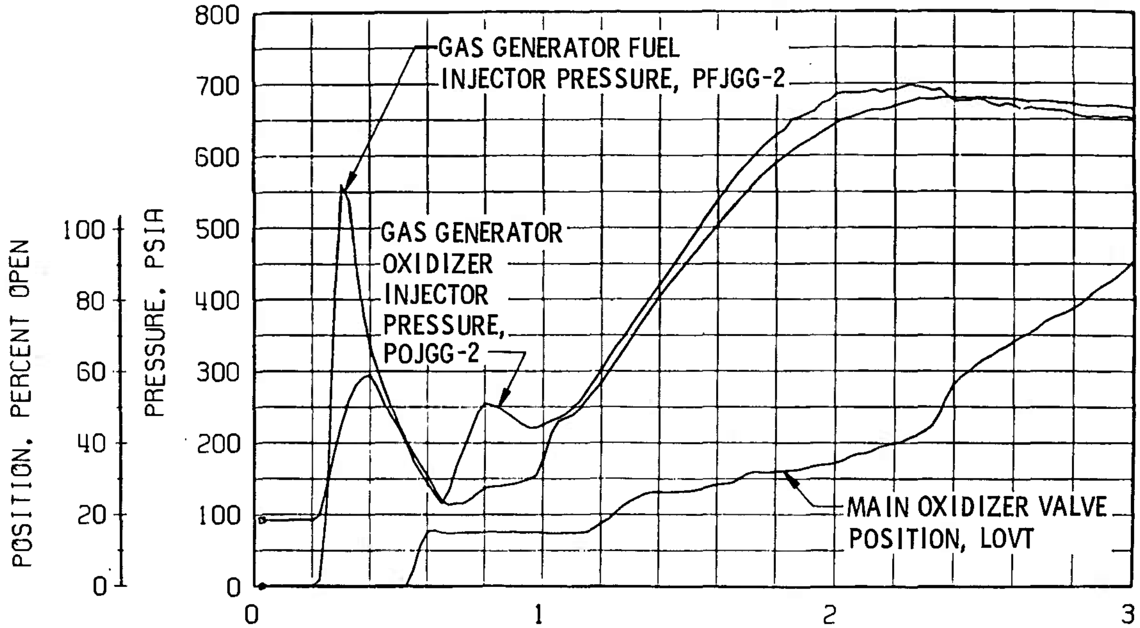


c. Thrust Chamber Fuel System, Shutdown

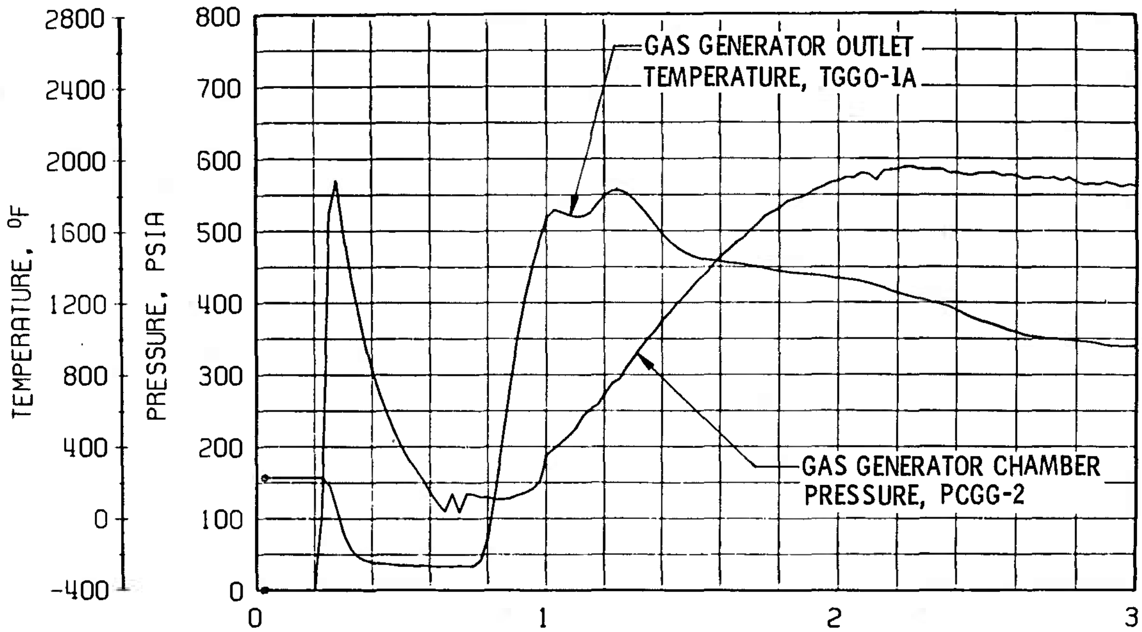


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 41 Continued

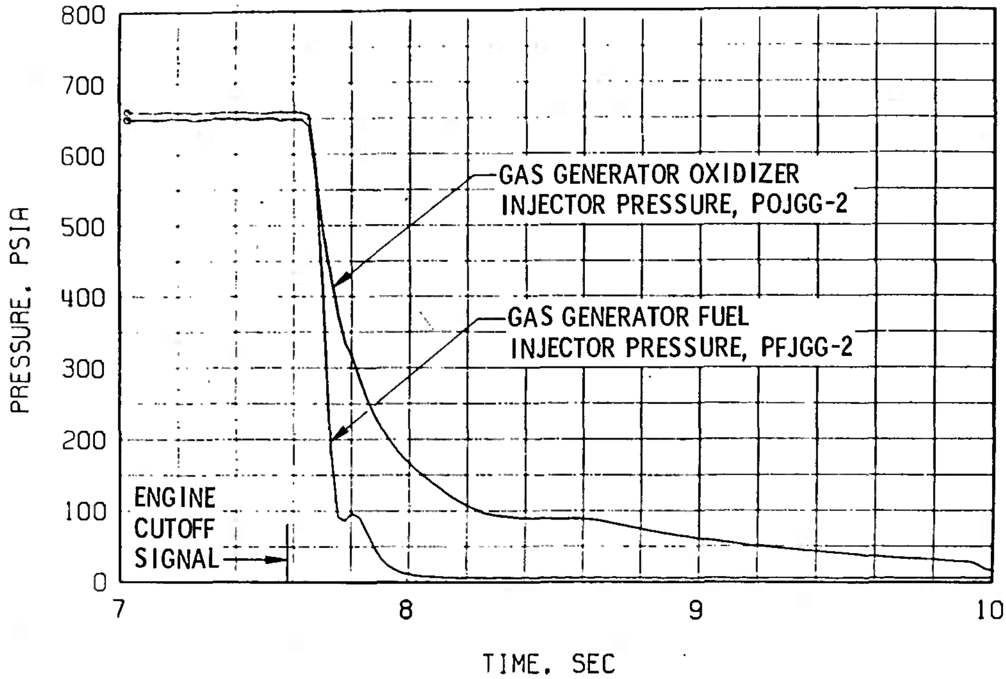


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

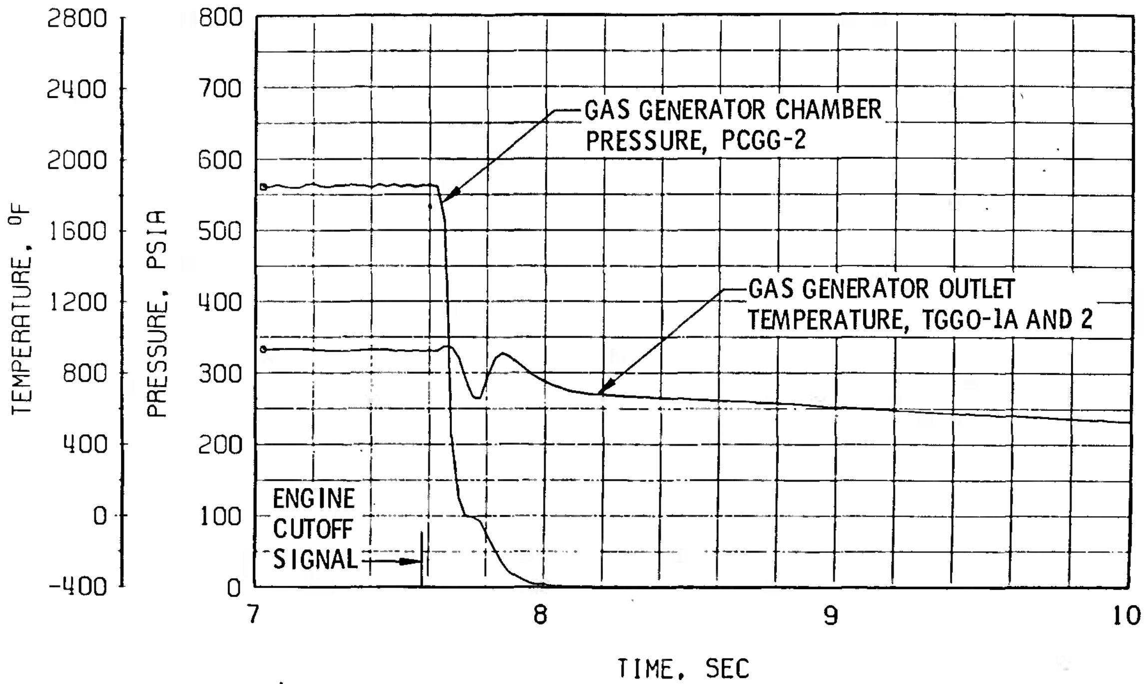


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 41 Continued

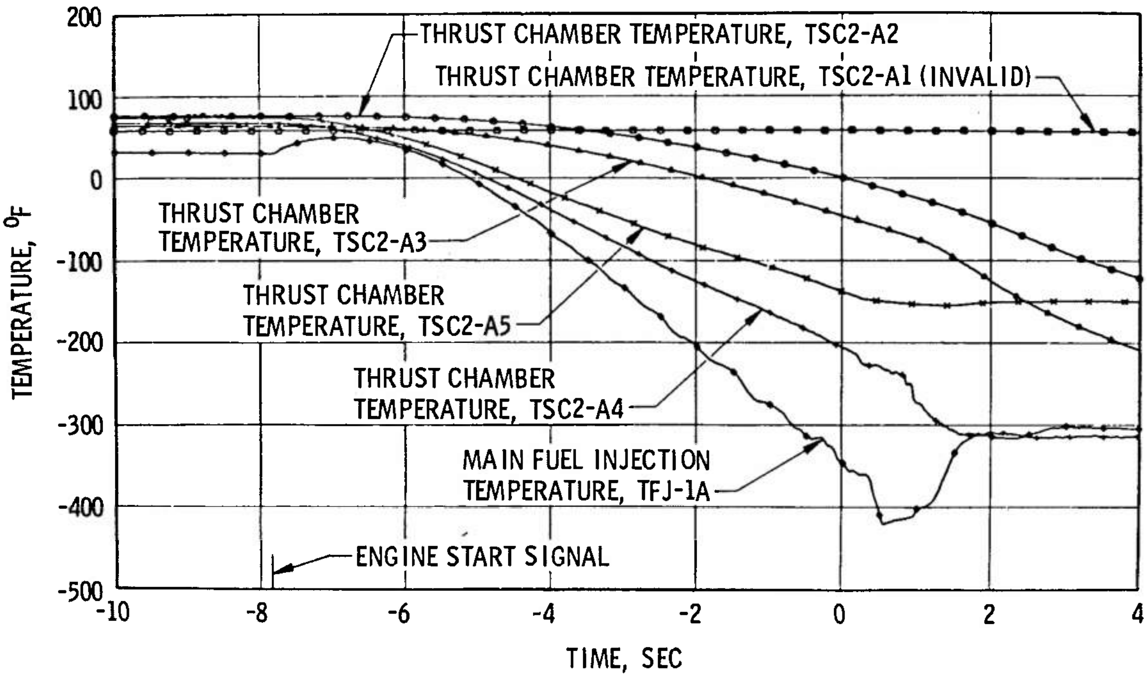


g. Gas Generator Injector Pressures, Shutdown

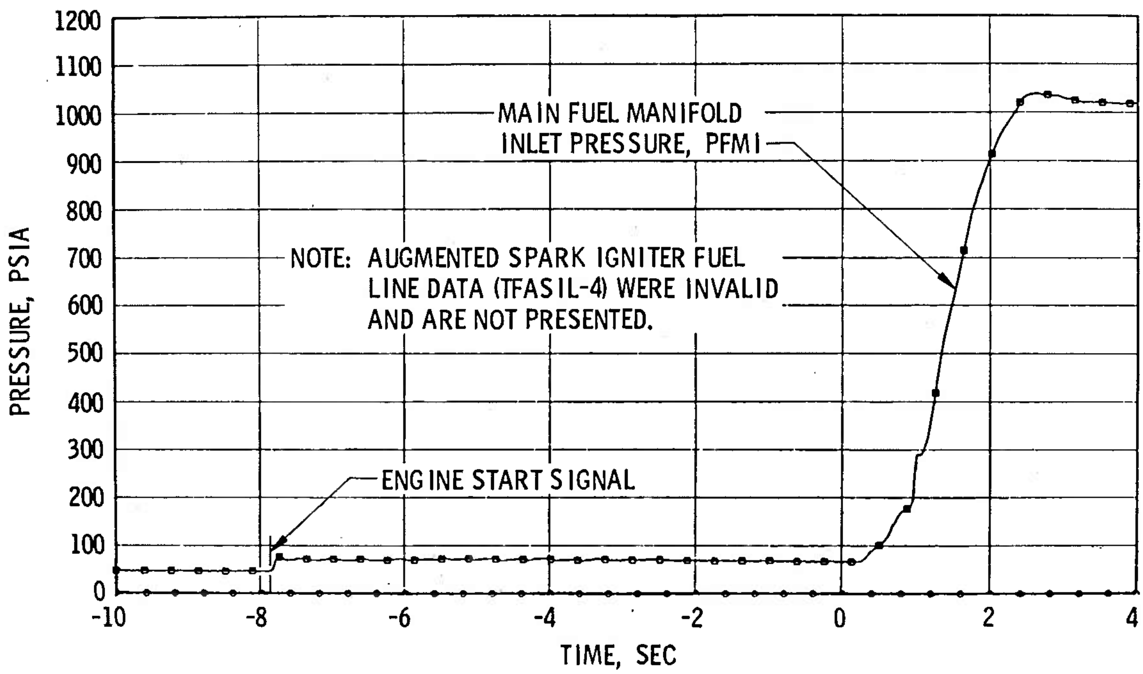


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 41 Continued

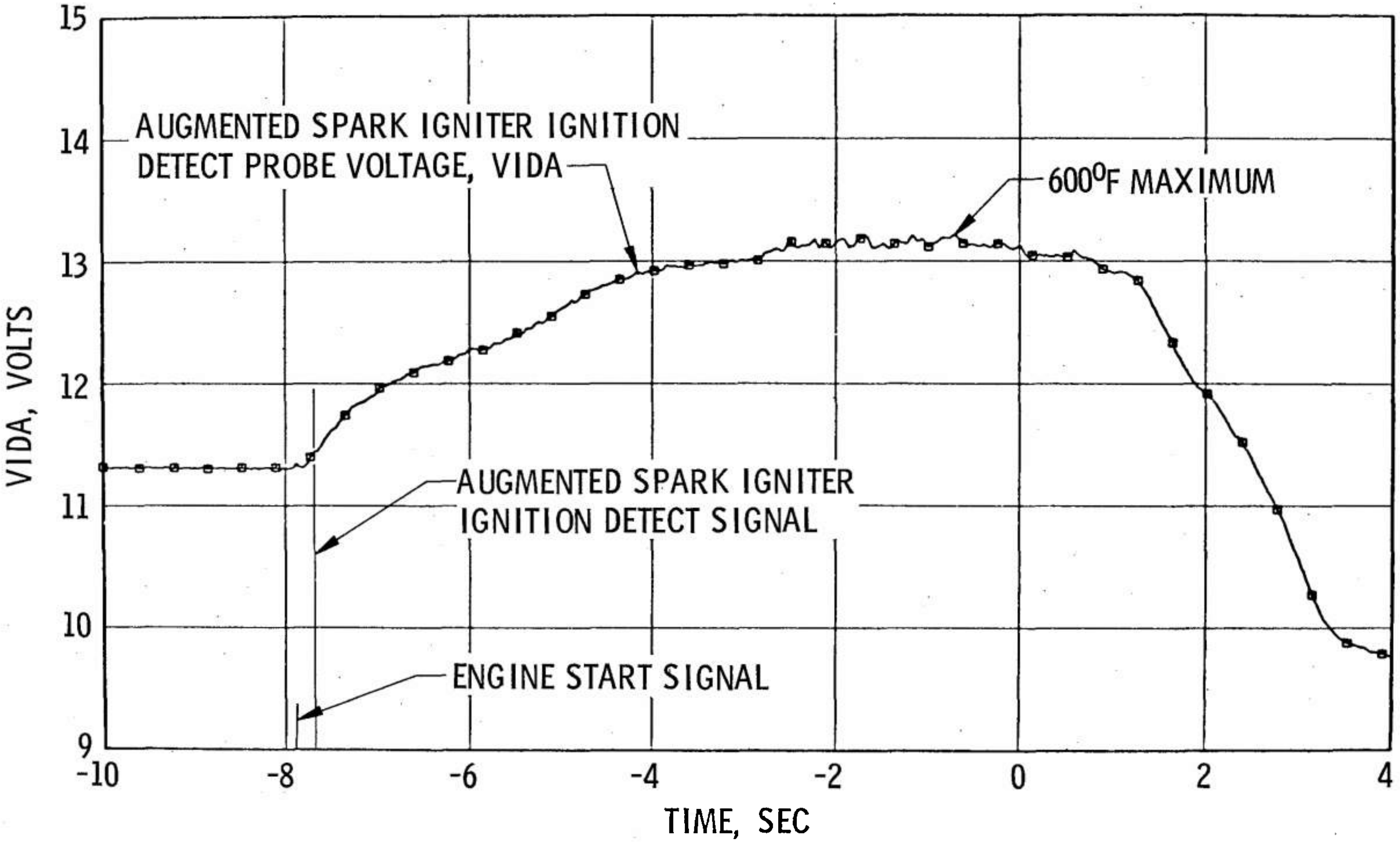


i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

Fig. 41 Continued



k. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 41 Concluded

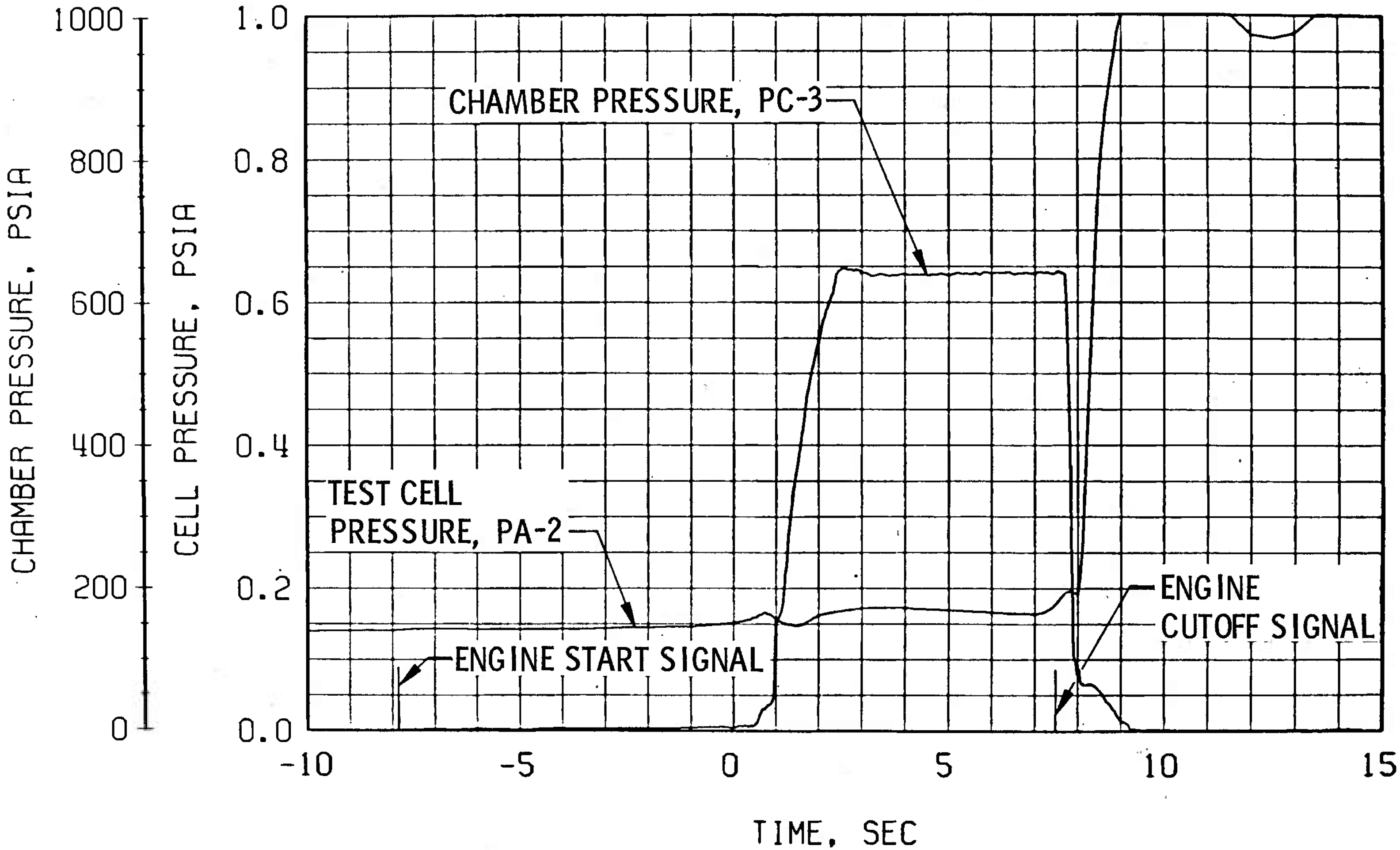


Fig. 42 Engine Ambient and Combustion Chamber Pressures, Firing 40B

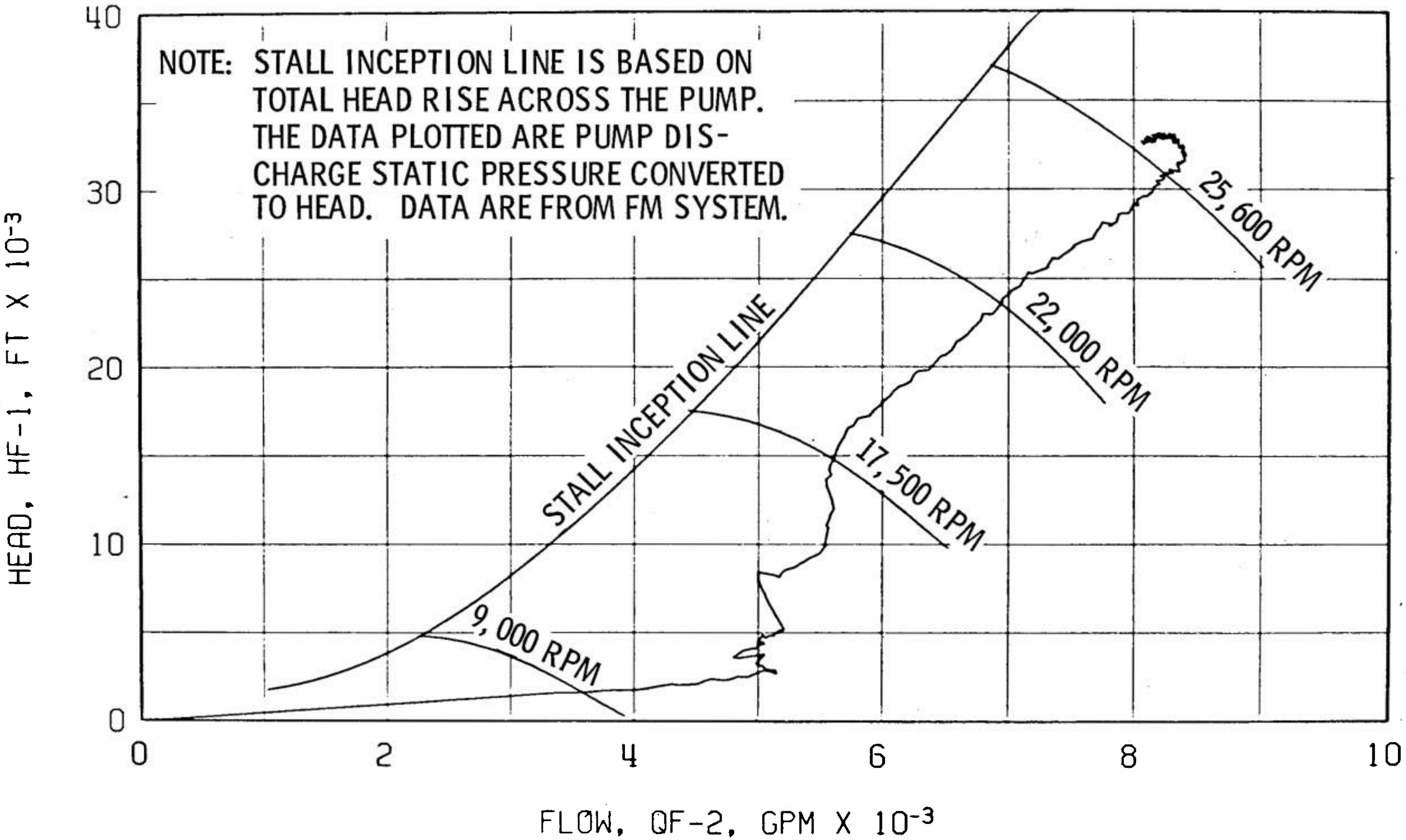
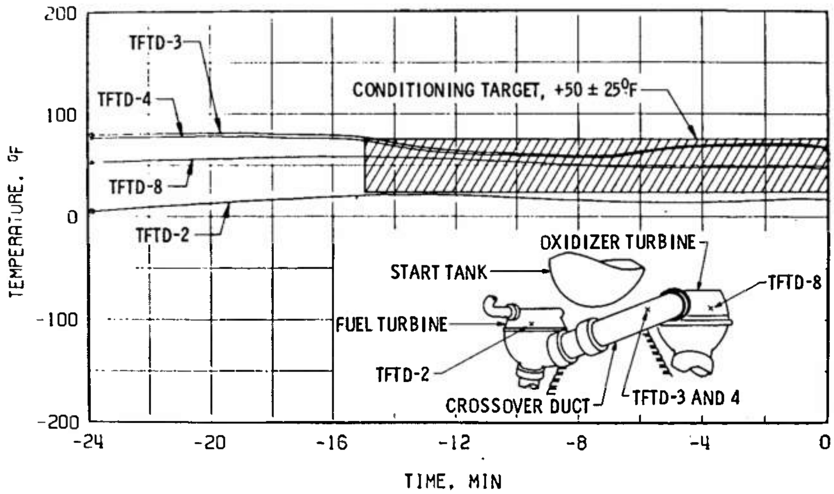
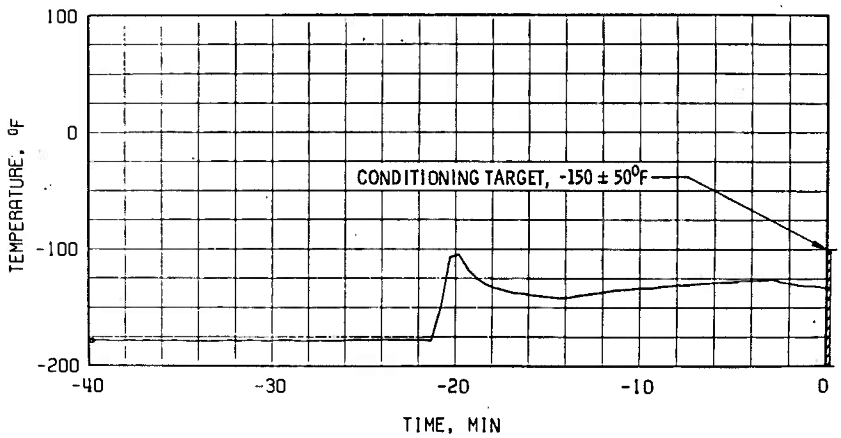


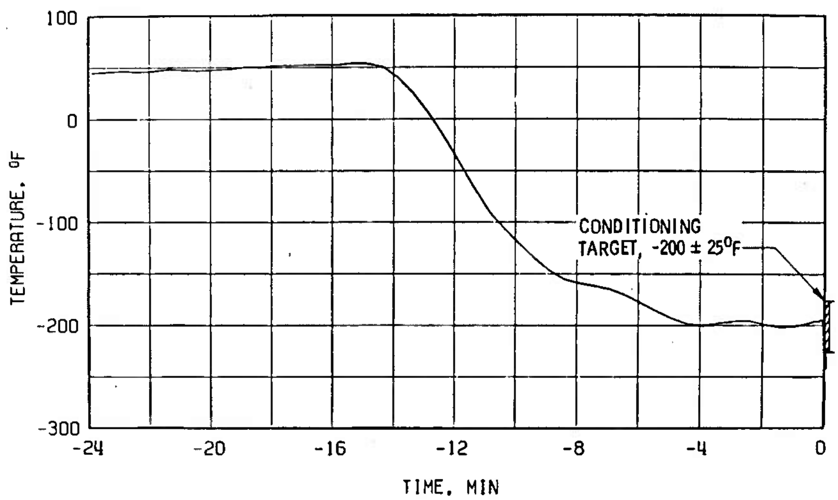
Fig. 43 Fuel Pump Start Transient Performance, Firing 40B



a. Crossover Duct, TFTD

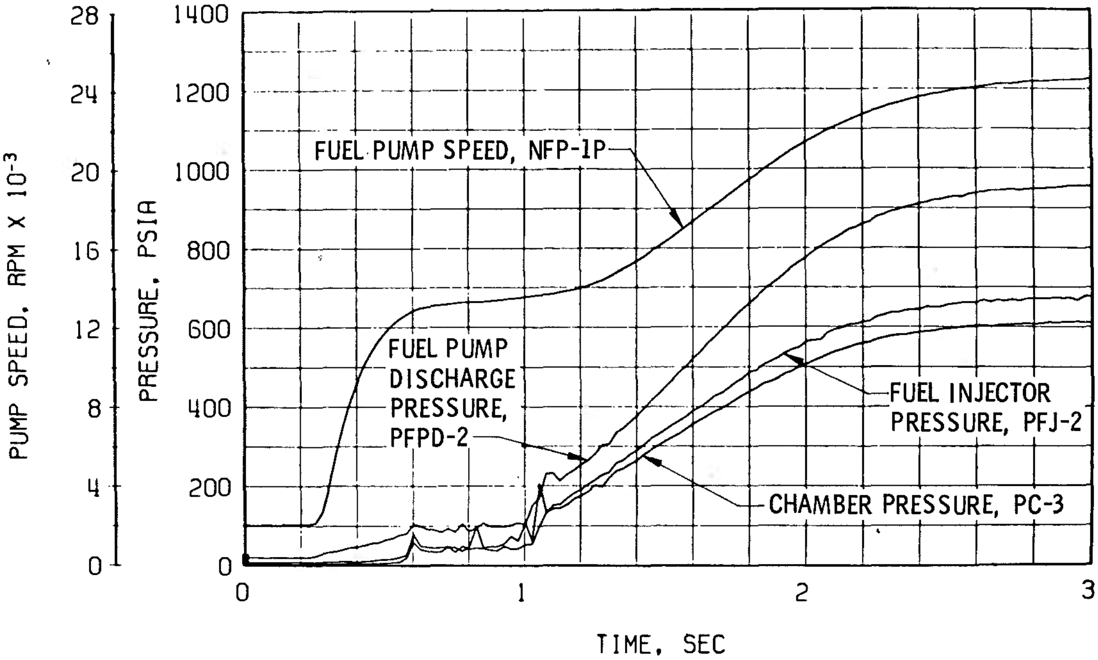


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

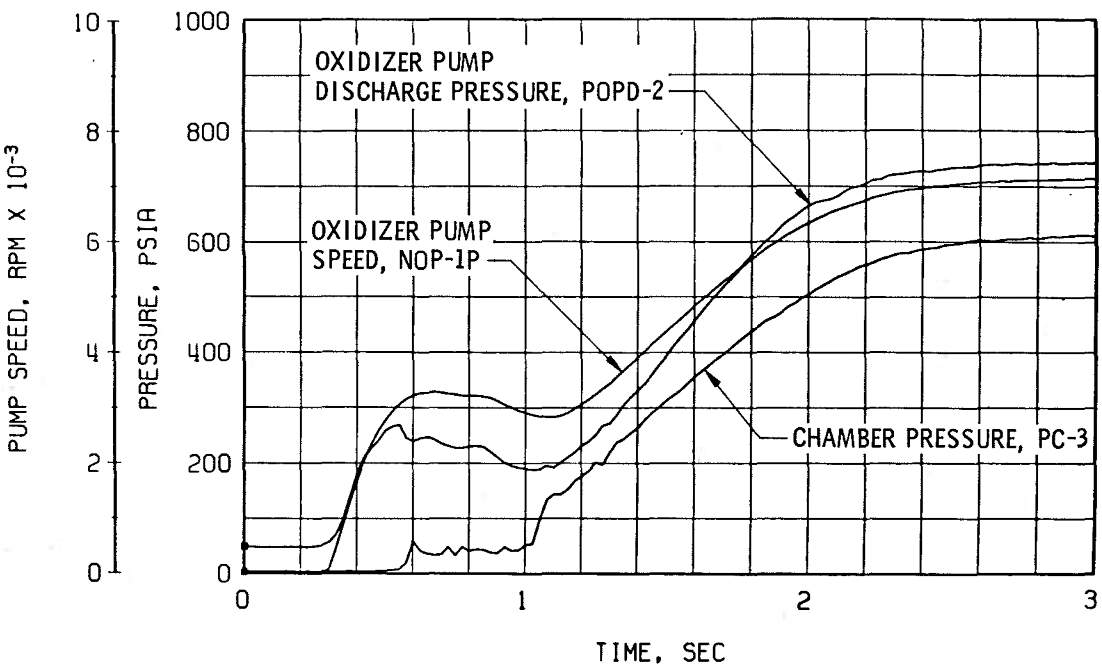


c. Thrust Chamber Throat, TTC-1P

Fig. 44 Thermal Conditioning History of Engine Components, Firing 40C

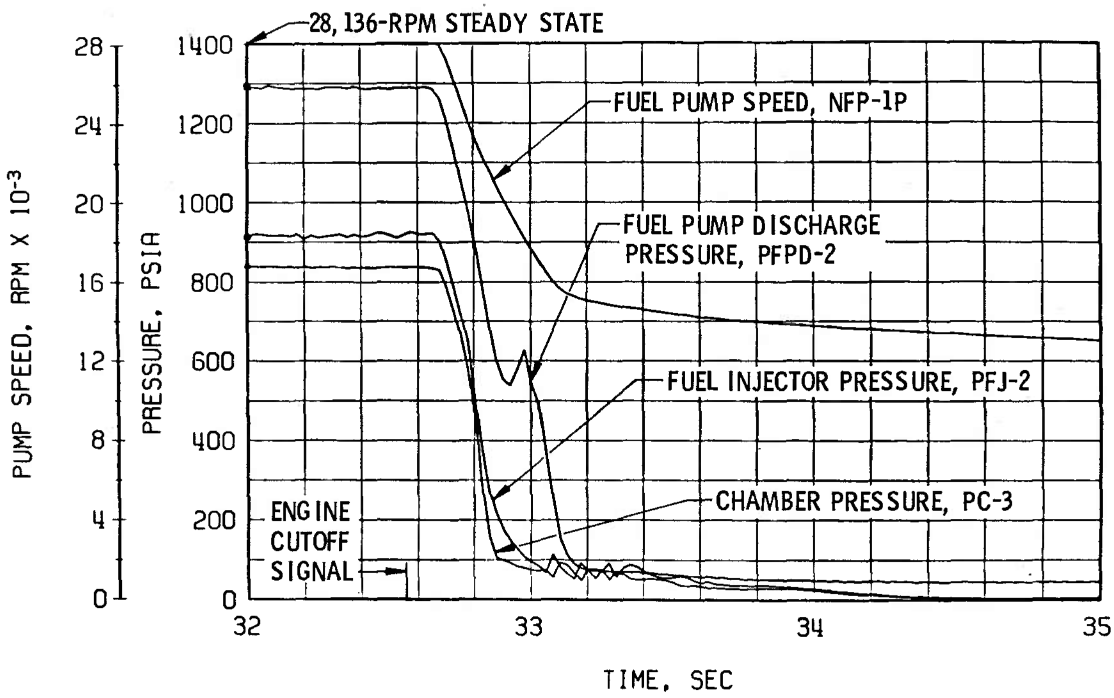


a. Thrust Chamber Fuel System, Start

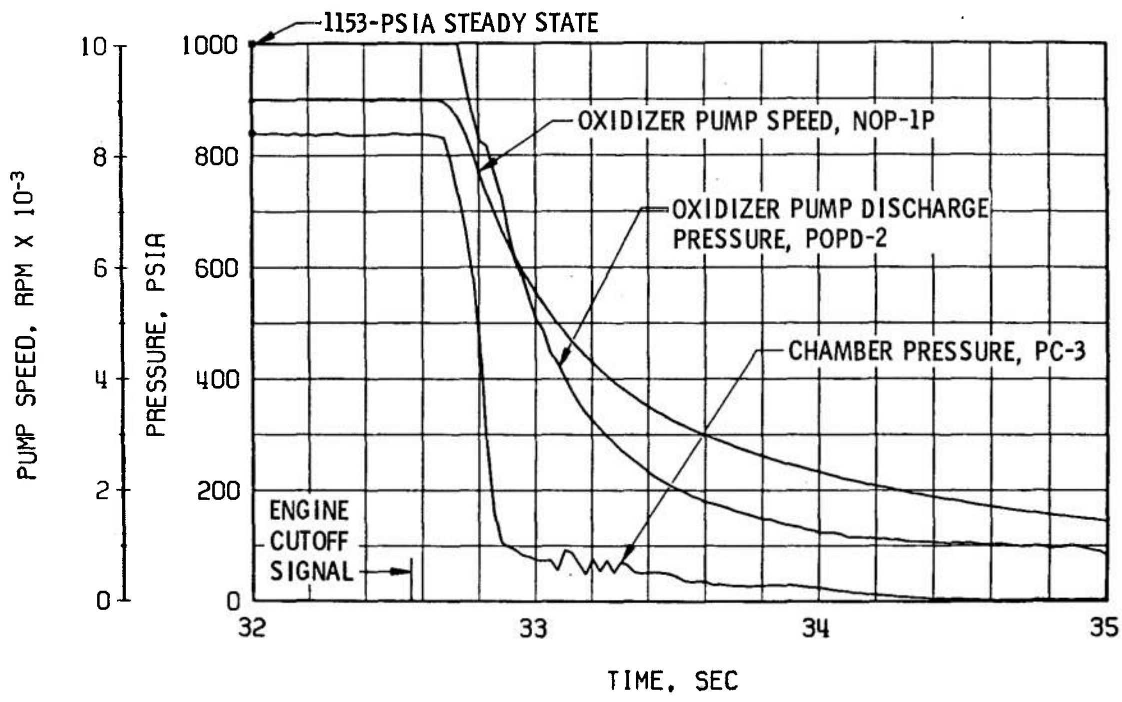


b. Thrust Chamber Oxidizer System, Start

Fig. 45 Engine Transient Operation, Firing 40C

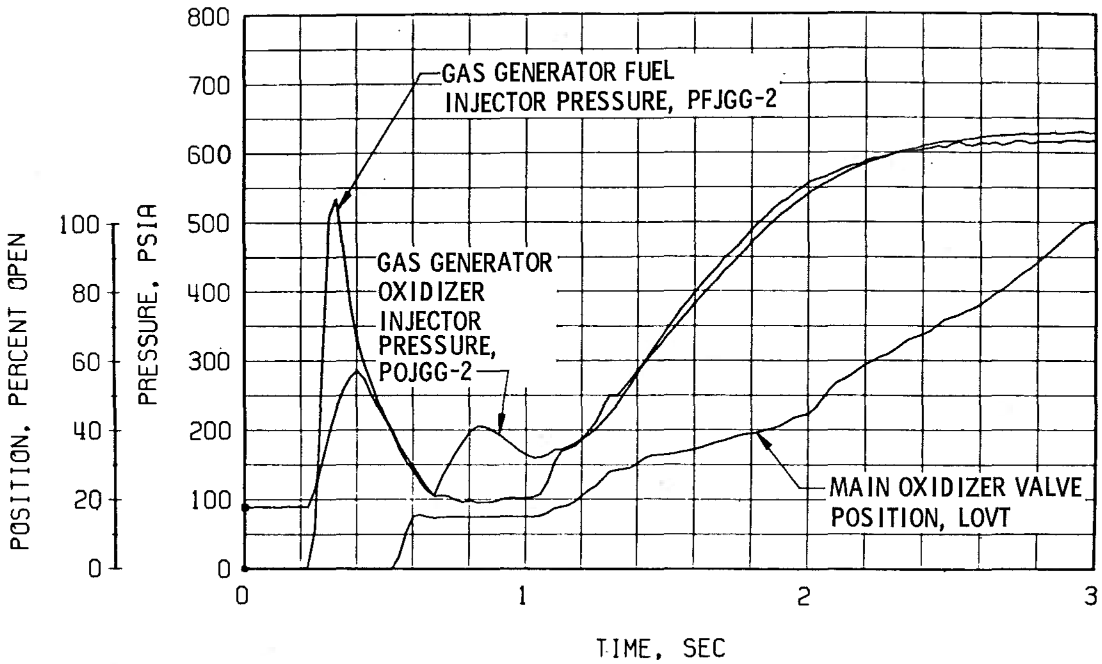


c. **Thrust Chamber Fuel System, Shutdown**

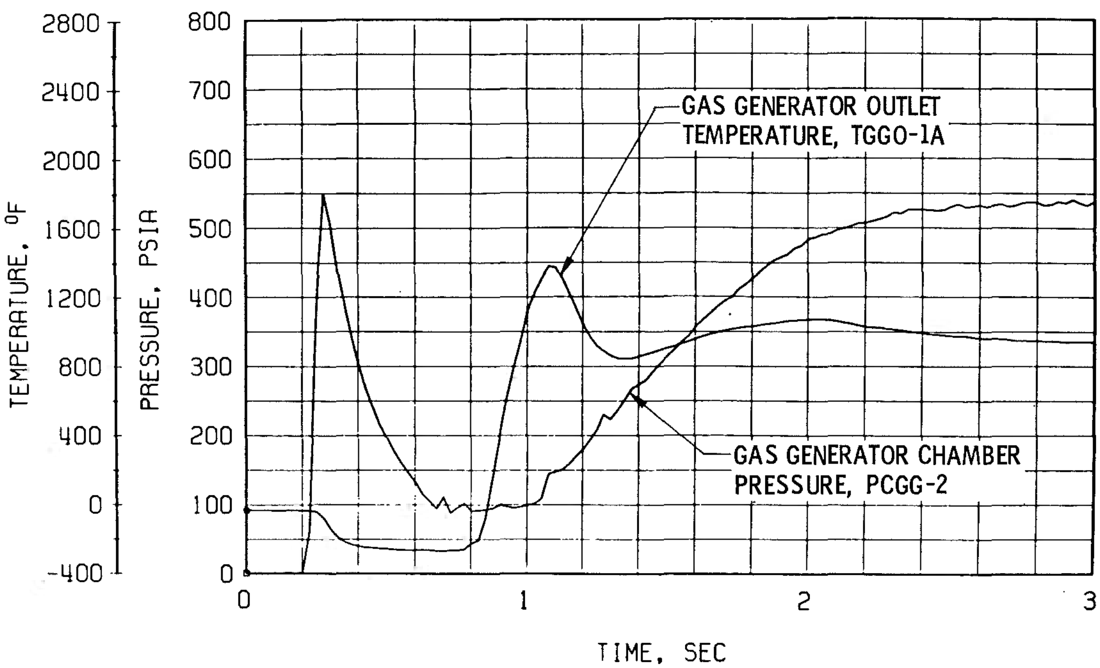


d. **Thrust Chamber Oxidizer System, Shutdown**

Fig. 45 Continued

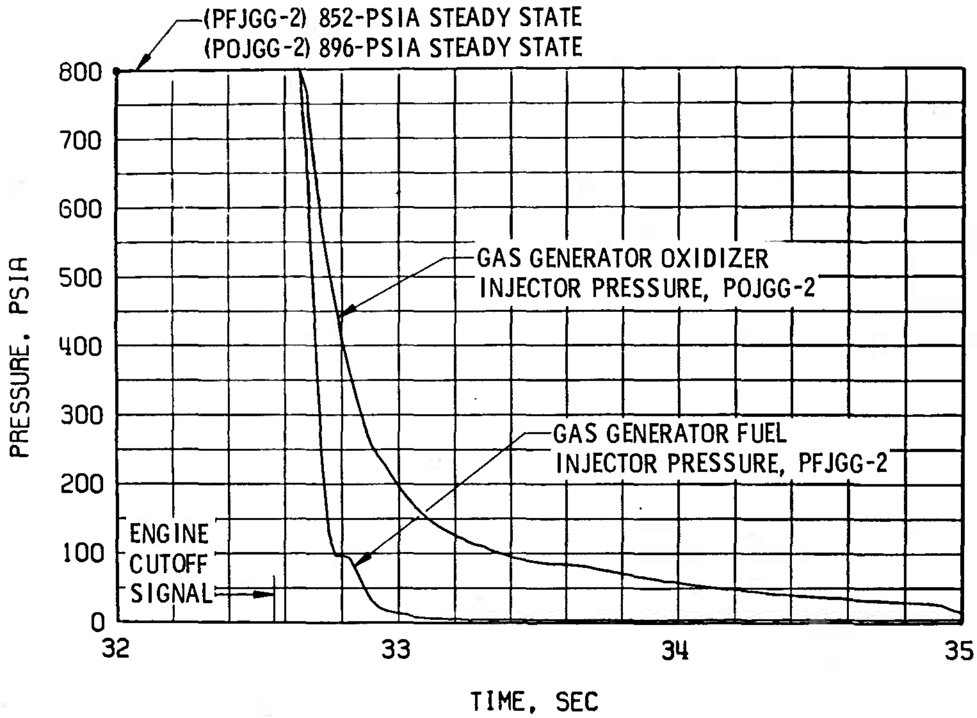


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

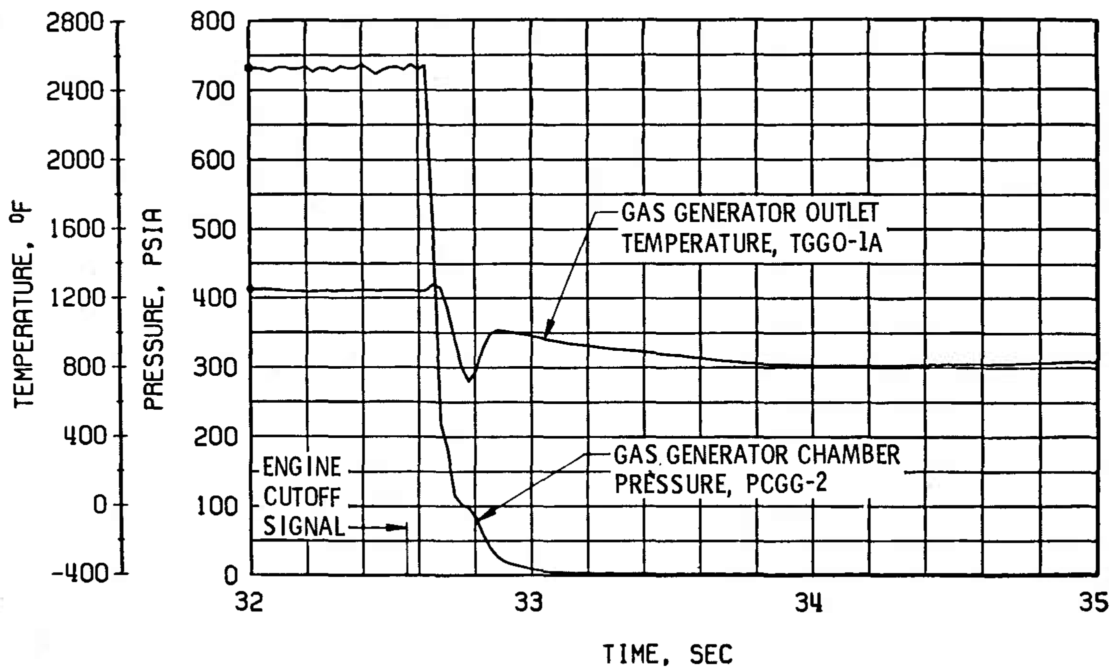


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 45 Continued

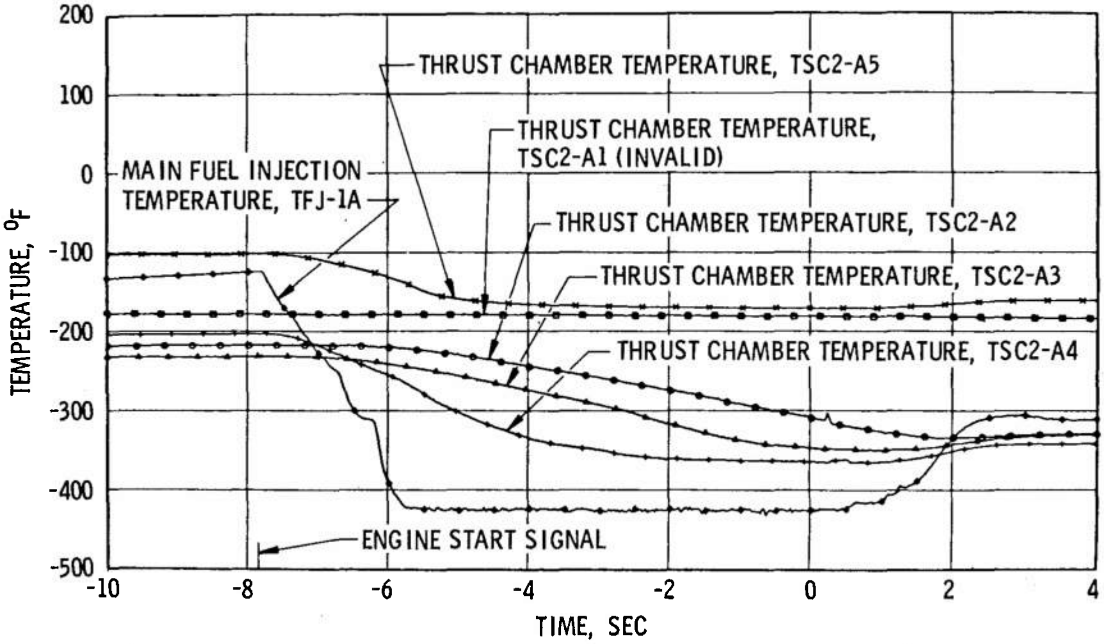


g. Gas Generator Injector Pressures, Shutdown

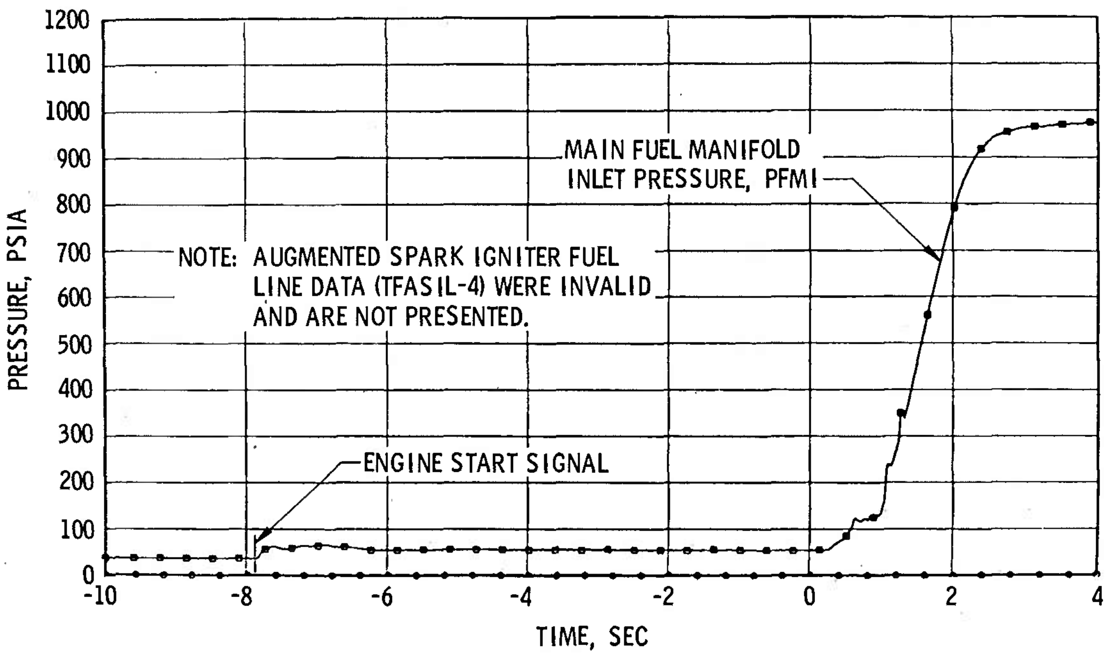


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 45 Continued

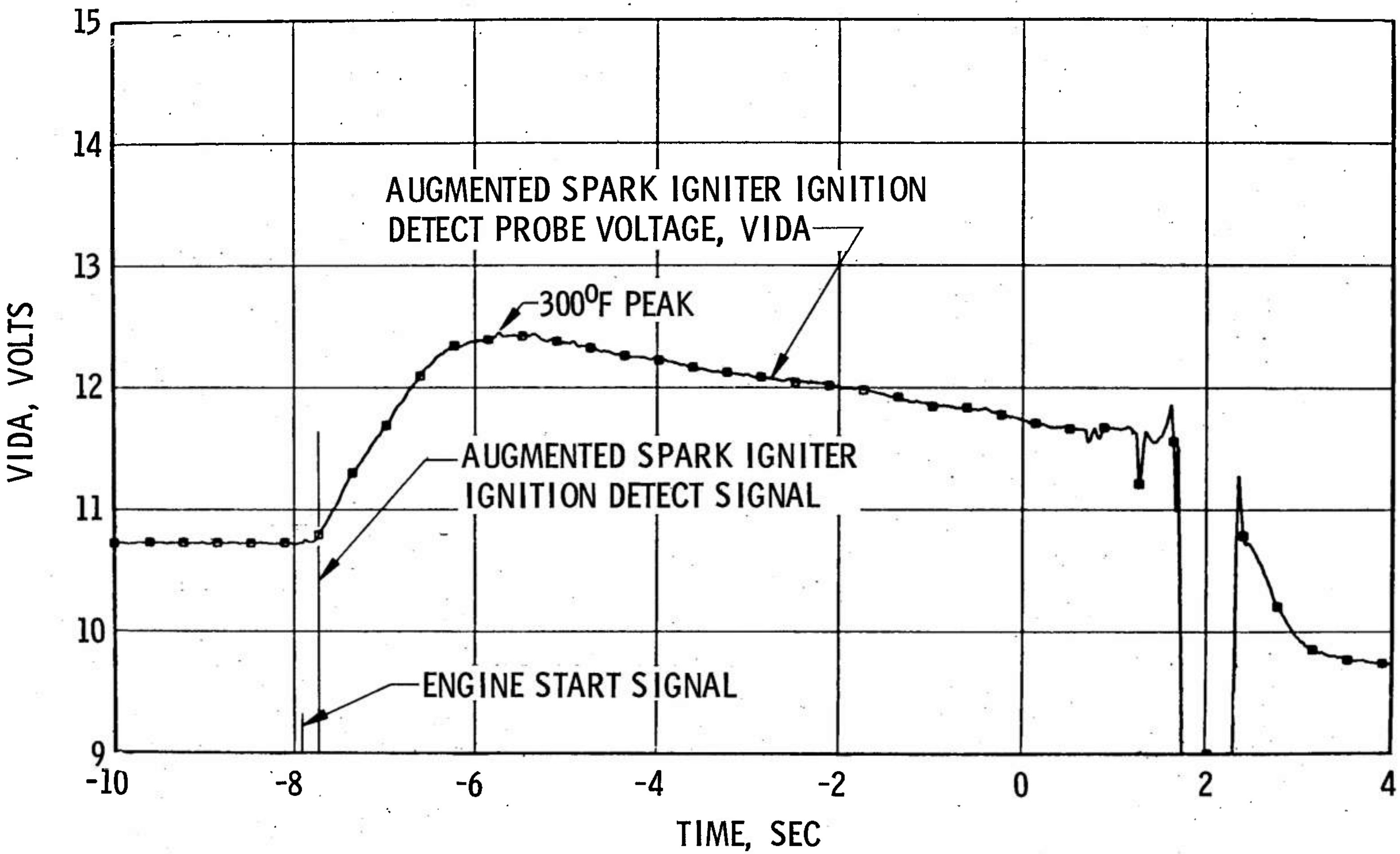


i. Thrust Chamber Temperature Transient, Start



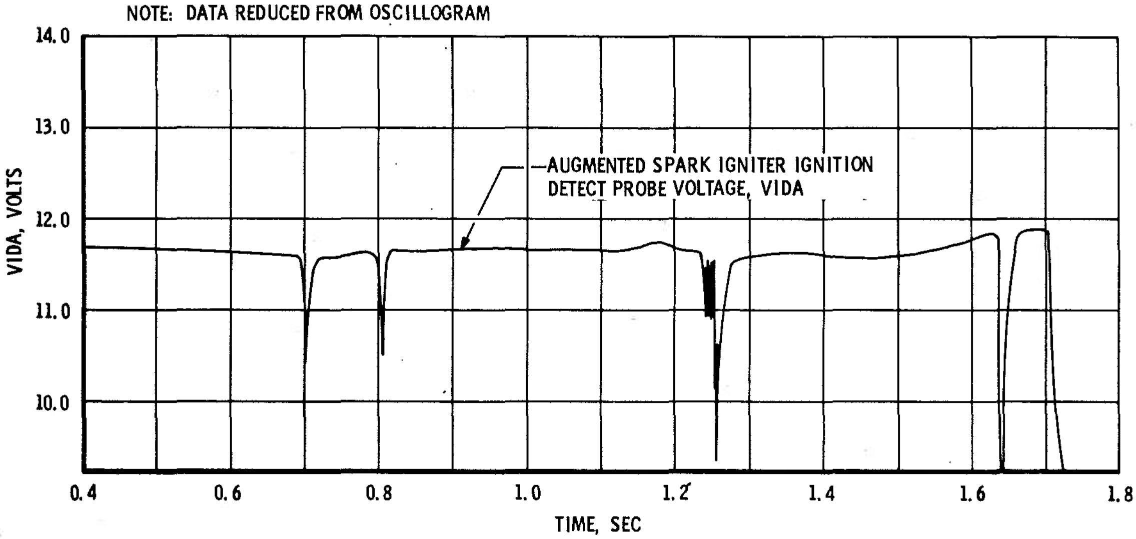
j. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

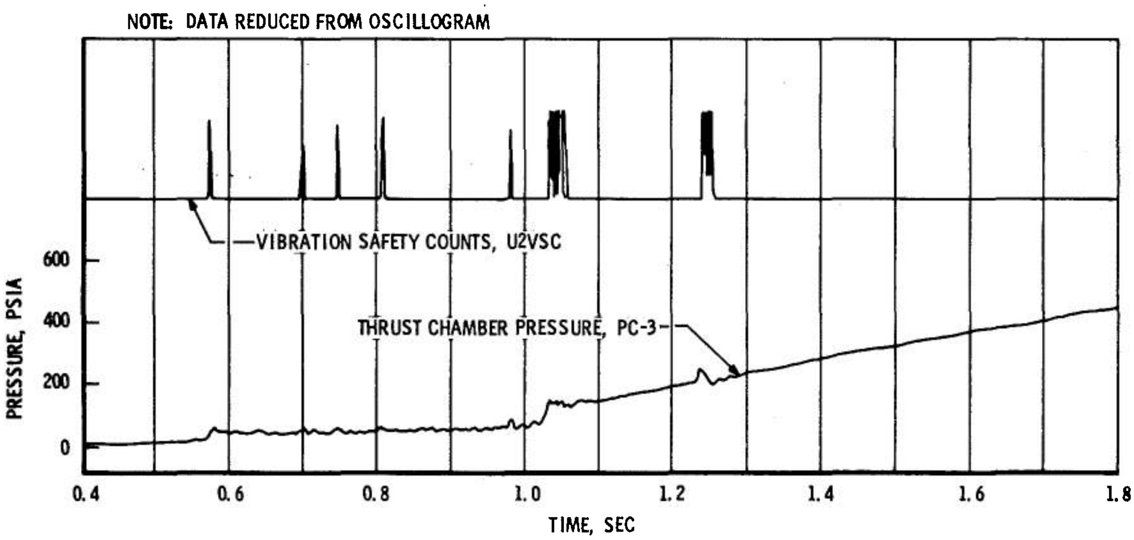
Fig. 45 Continued



k. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 45 Continued





l. Augmented Spark Igniter Ignition Detect Probe Voltage and Thrust Chamber Ignition Transient

Fig. 45 Concluded

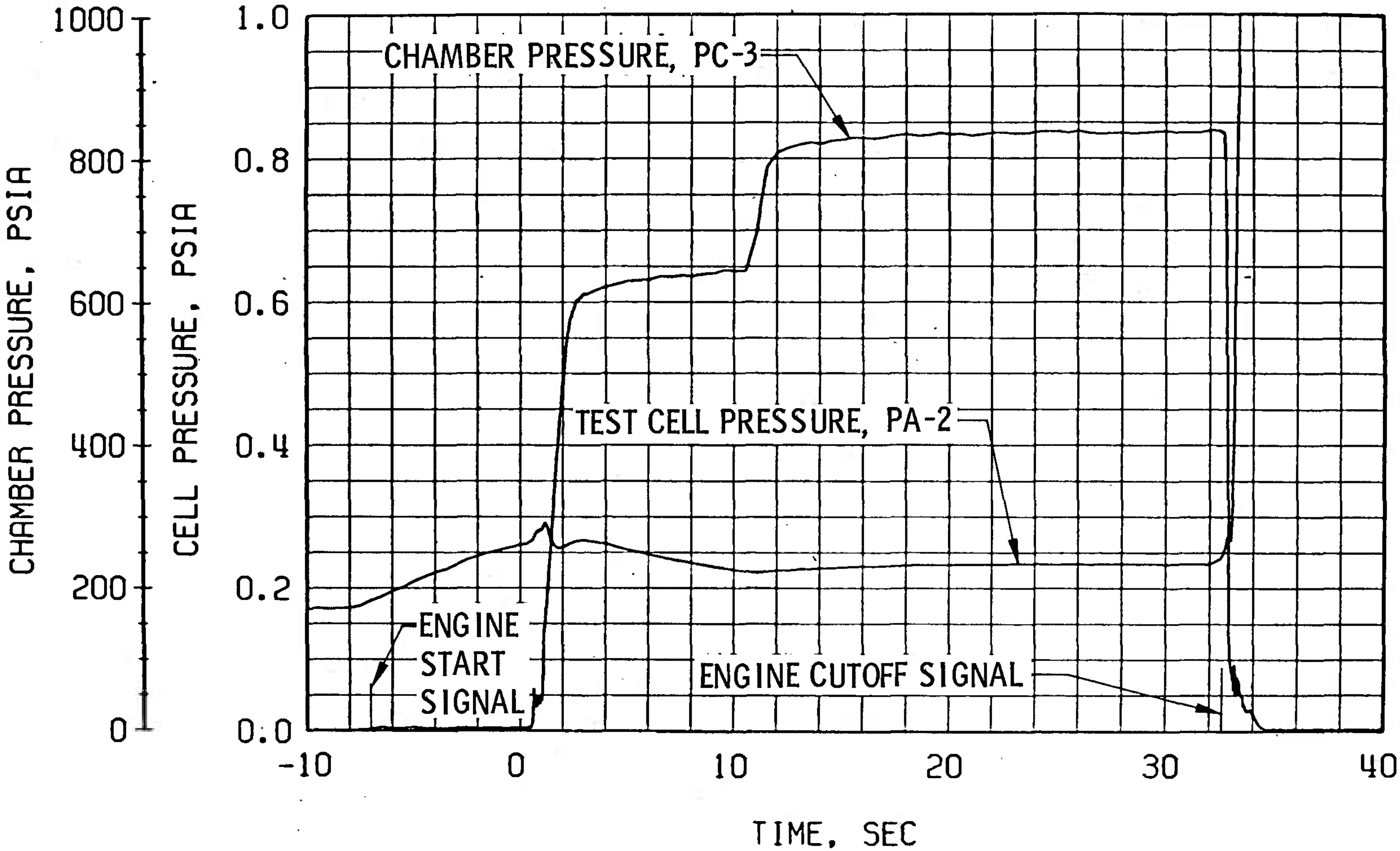


Fig. 46 Engine Ambient and Combustion Chamber Pressures, Firing 40C

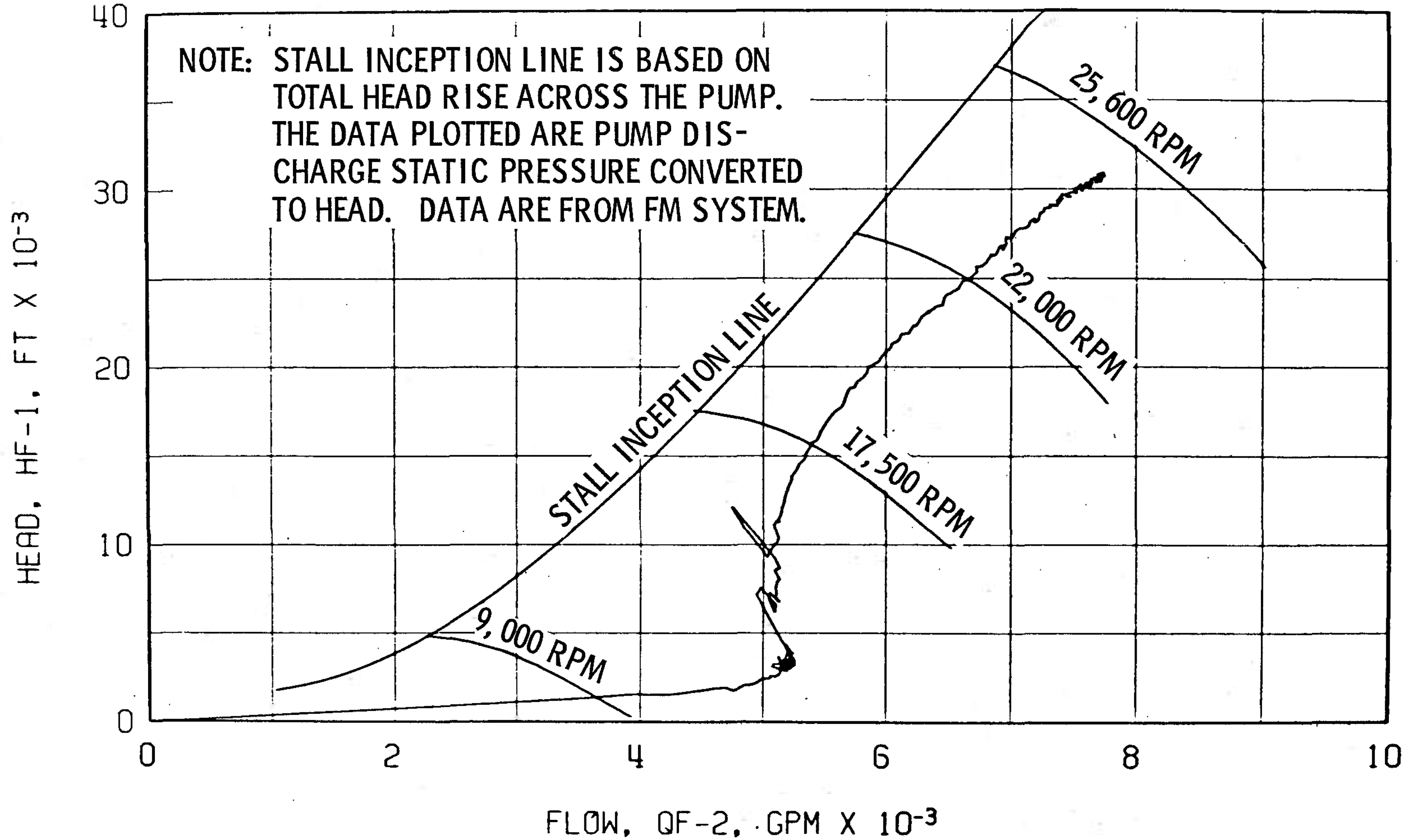
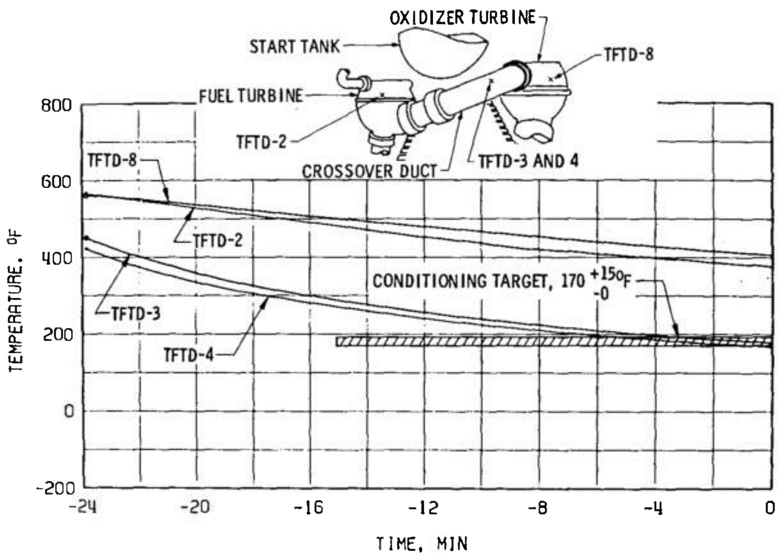
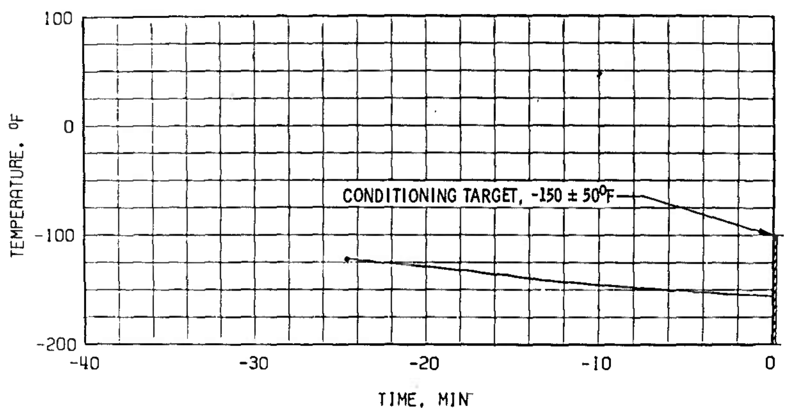


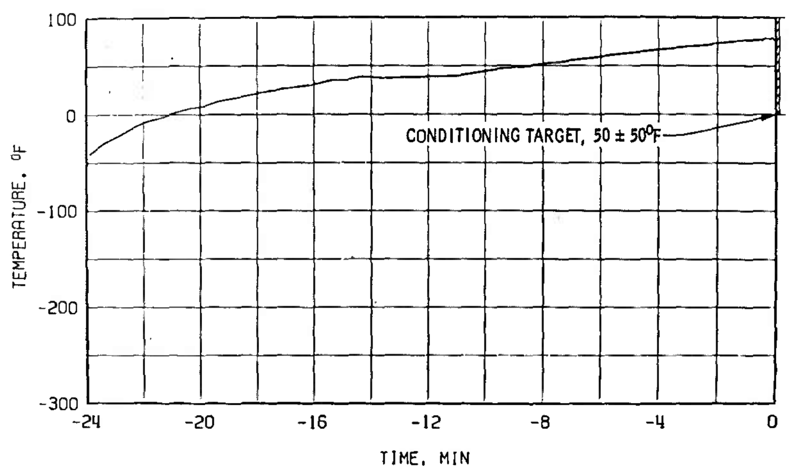
Fig. 47 Fuel Pump Start Transient Performance, Firing 40C



a. Crossover Duct, TFTD

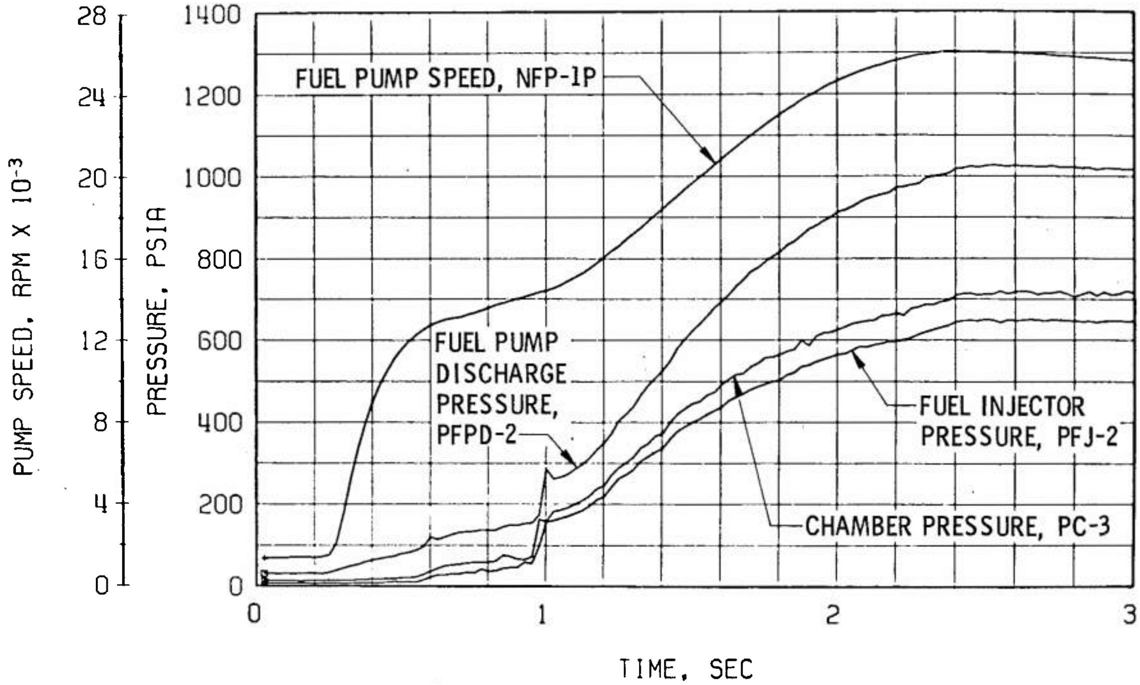


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

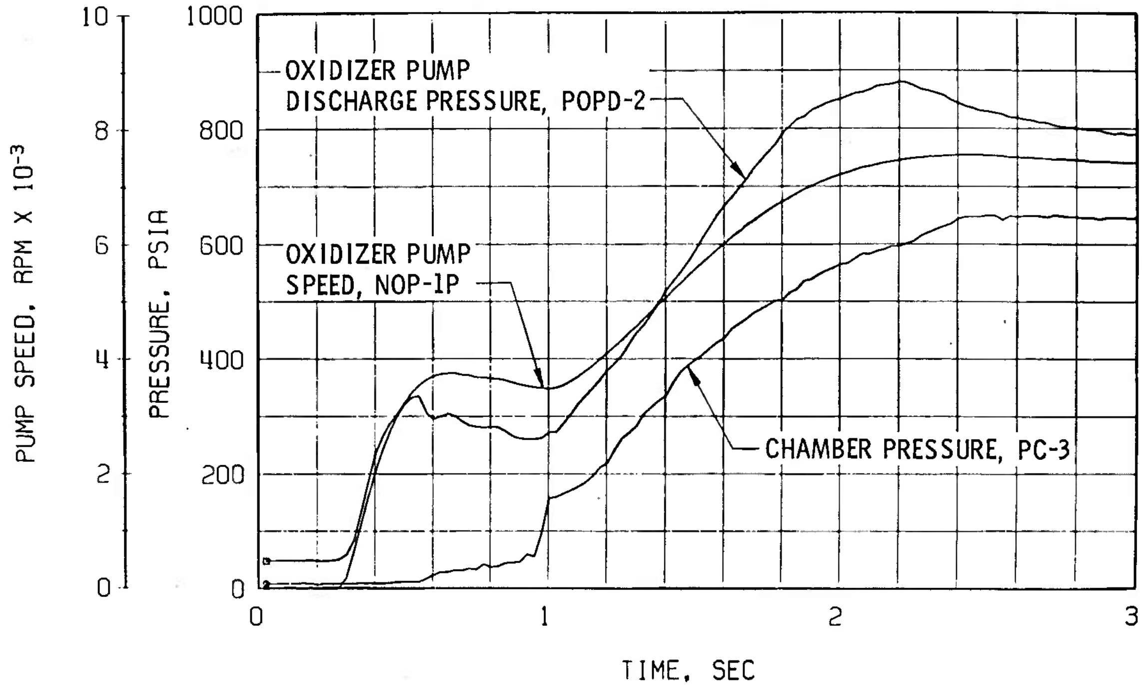


c. Thrust Chamber Throat, TTC-1P

Fig. 48 Thermal Conditioning History of Engine Components, Firing 40D

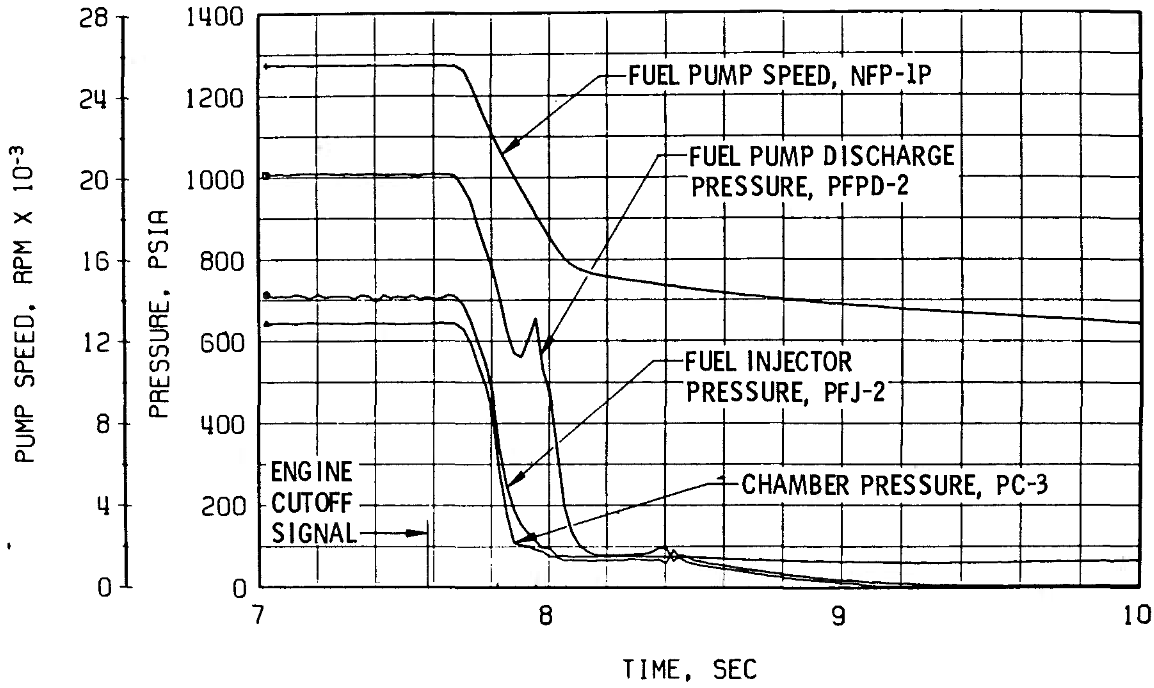


a. Thrust Chamber Fuel System, Start

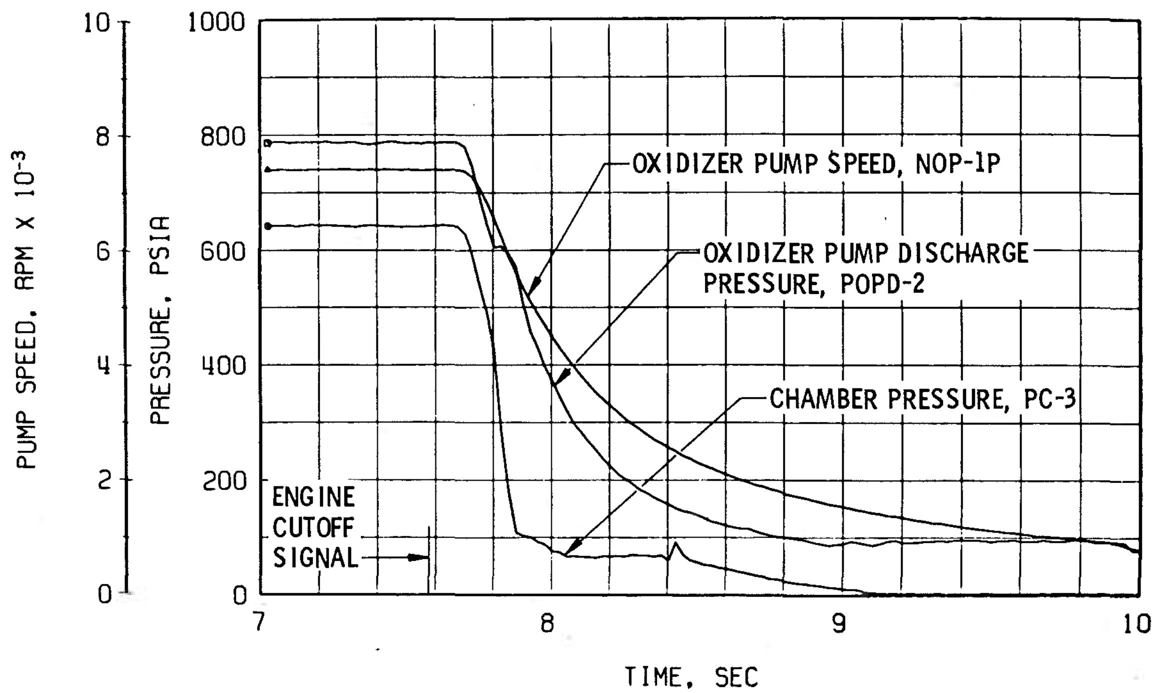


b. Thrust Chamber Oxidizer System, Start

Fig. 49 Engine Transient Operation, Firing 40D

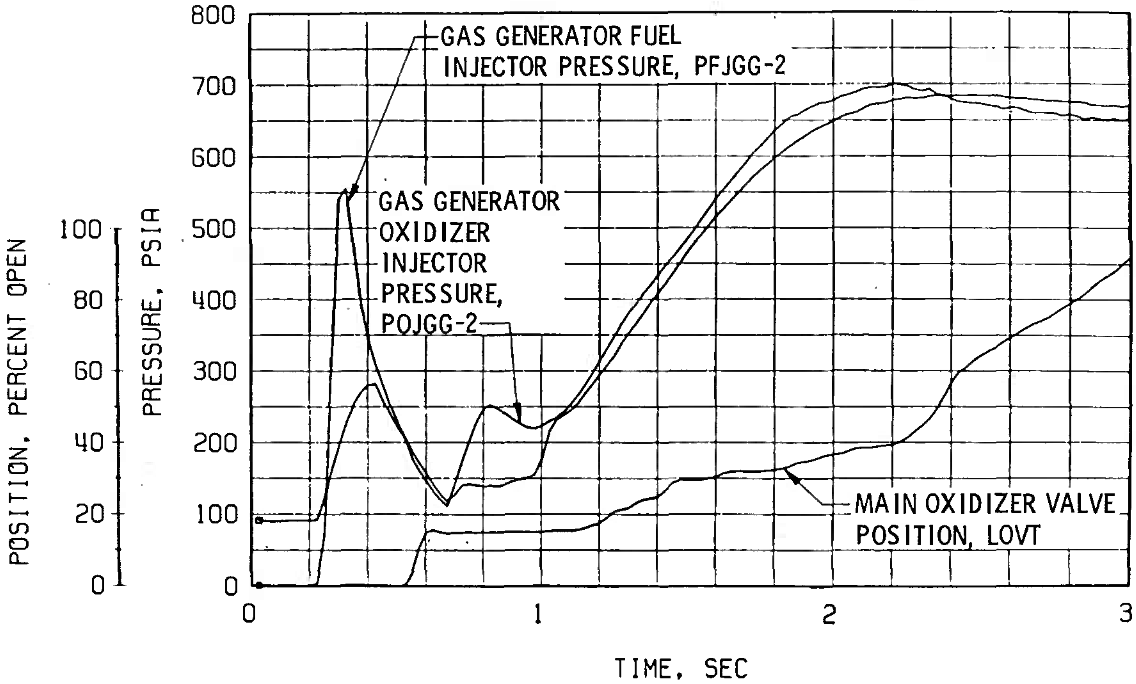


c. Thrust Chamber Fuel System, Shutdown

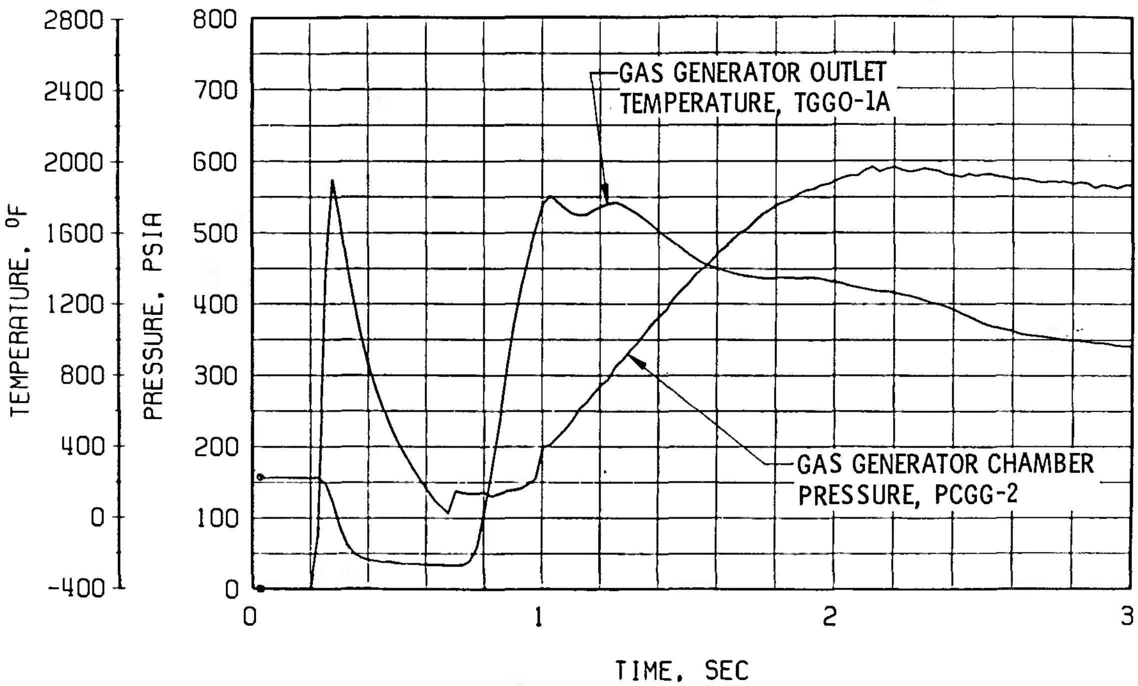


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 49 Continued

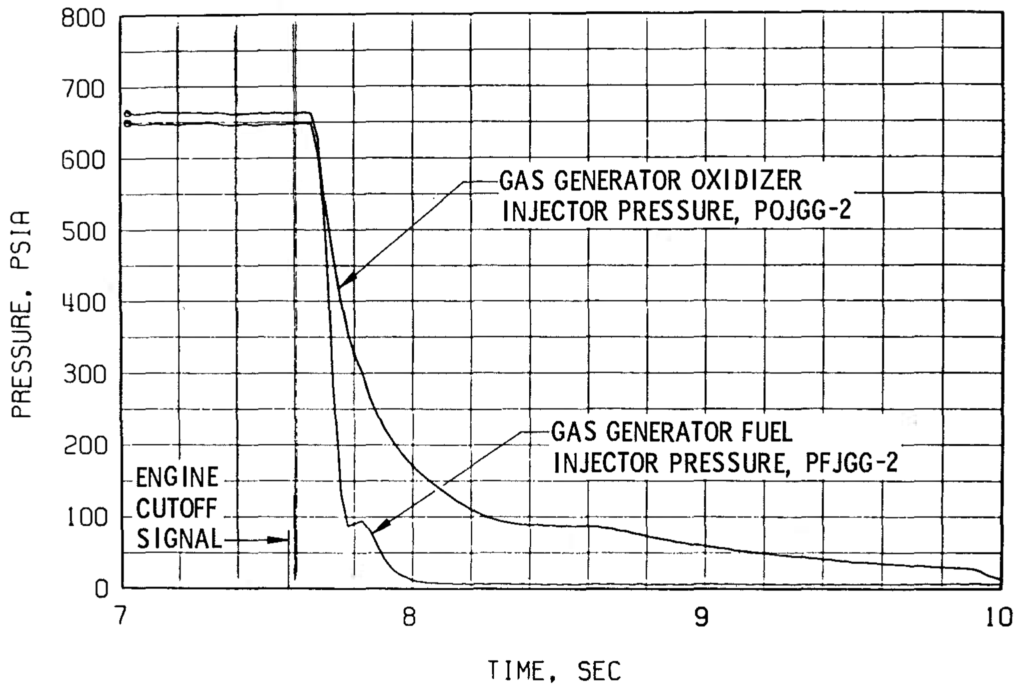


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

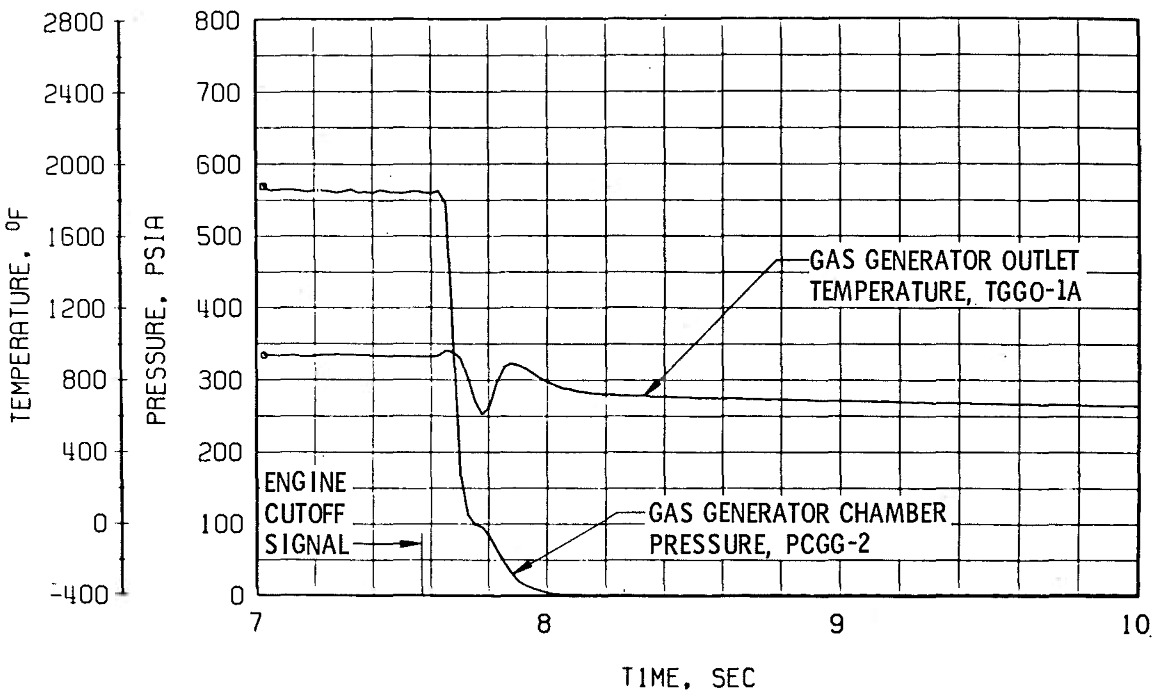


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 49 Continued

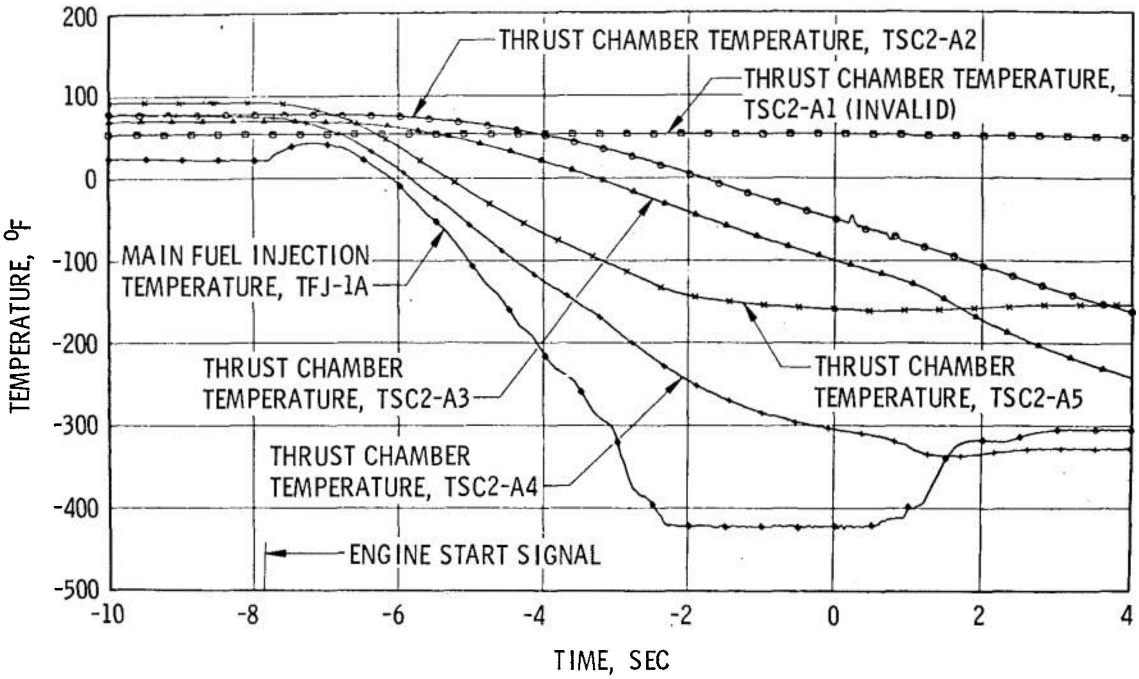


g. Gas Generator Injector Pressures, Shutdown

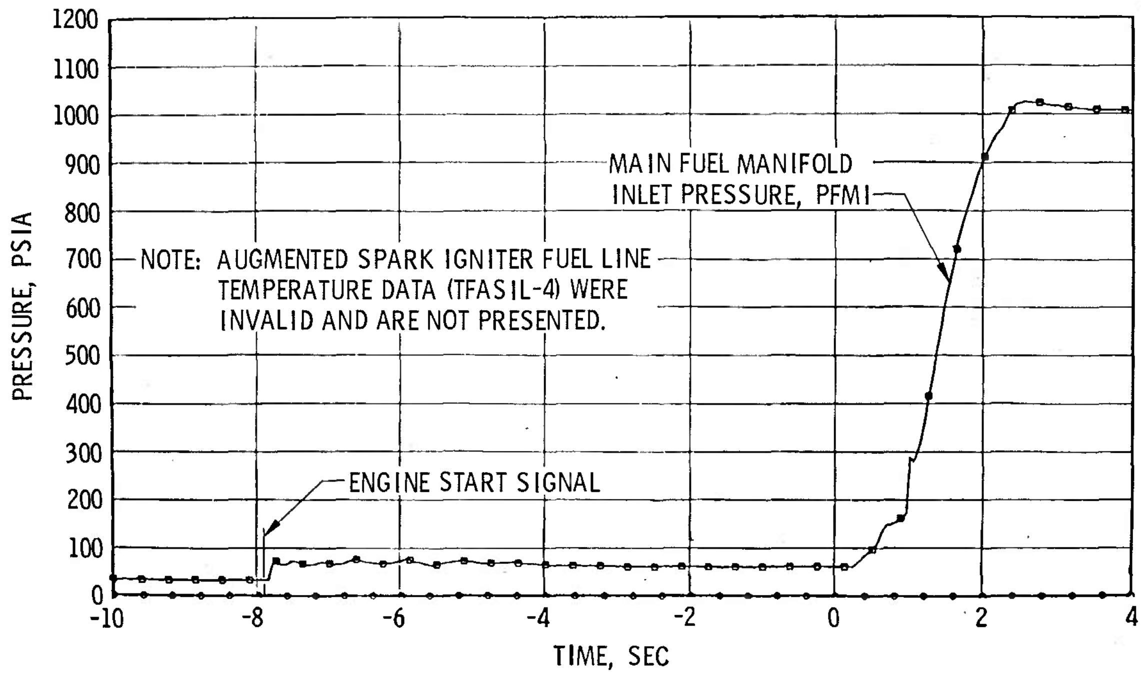


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 49 Continued

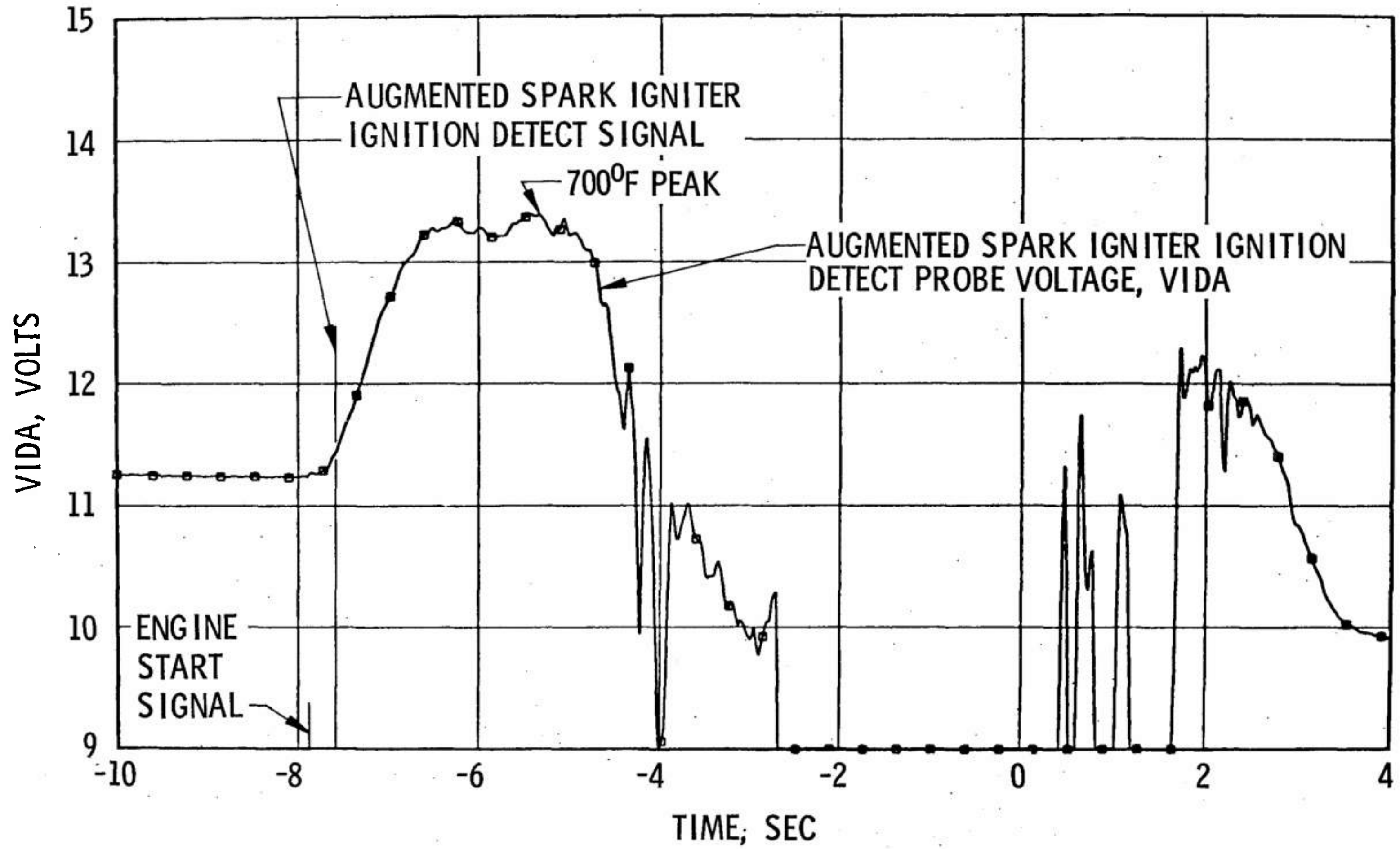


i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Pressure Transient, Start

Fig. 49 Continued



k. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 49 Concluded

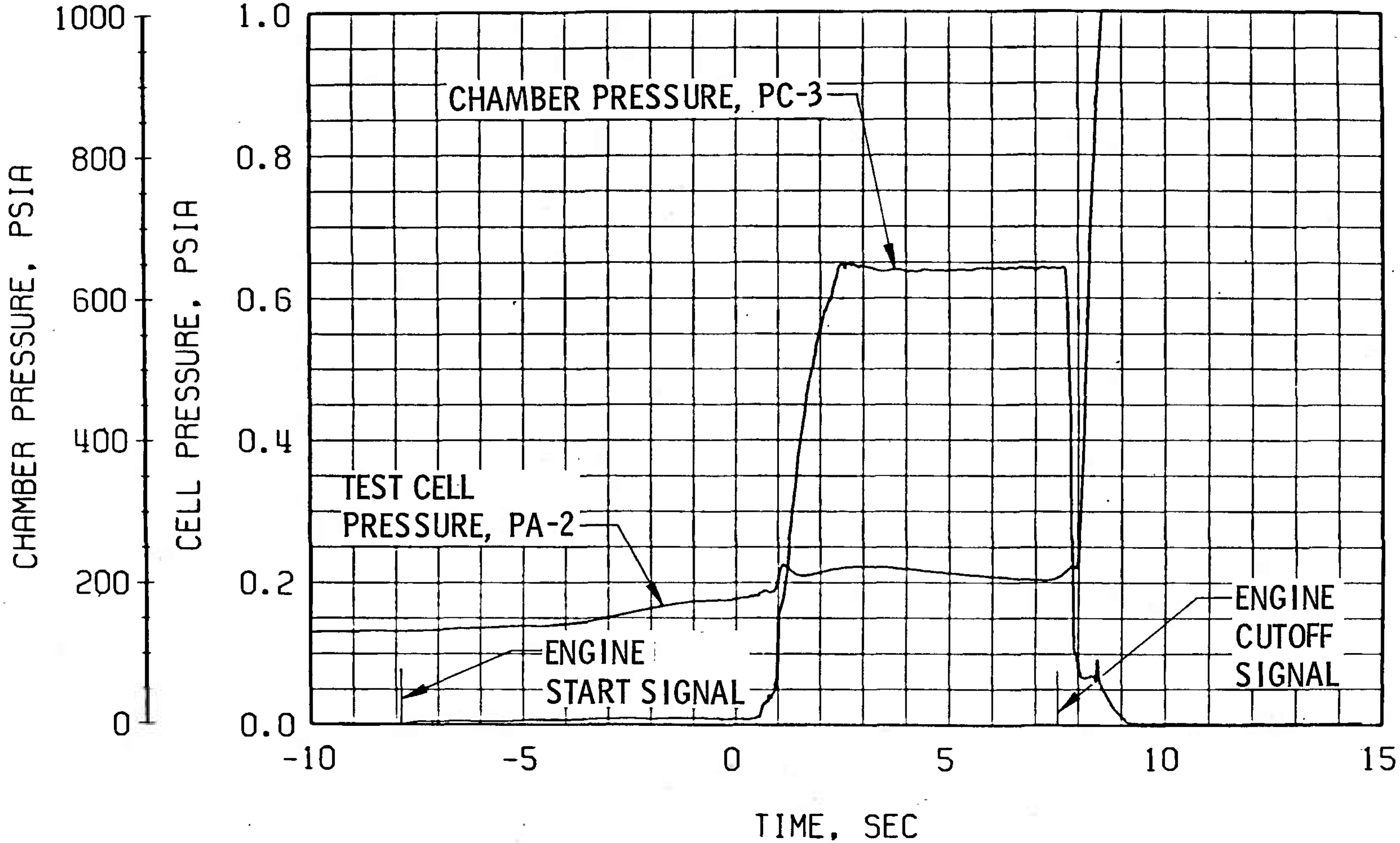


Fig. 50 Engine Ambient and Combustion Chamber Pressures, Firing 40D

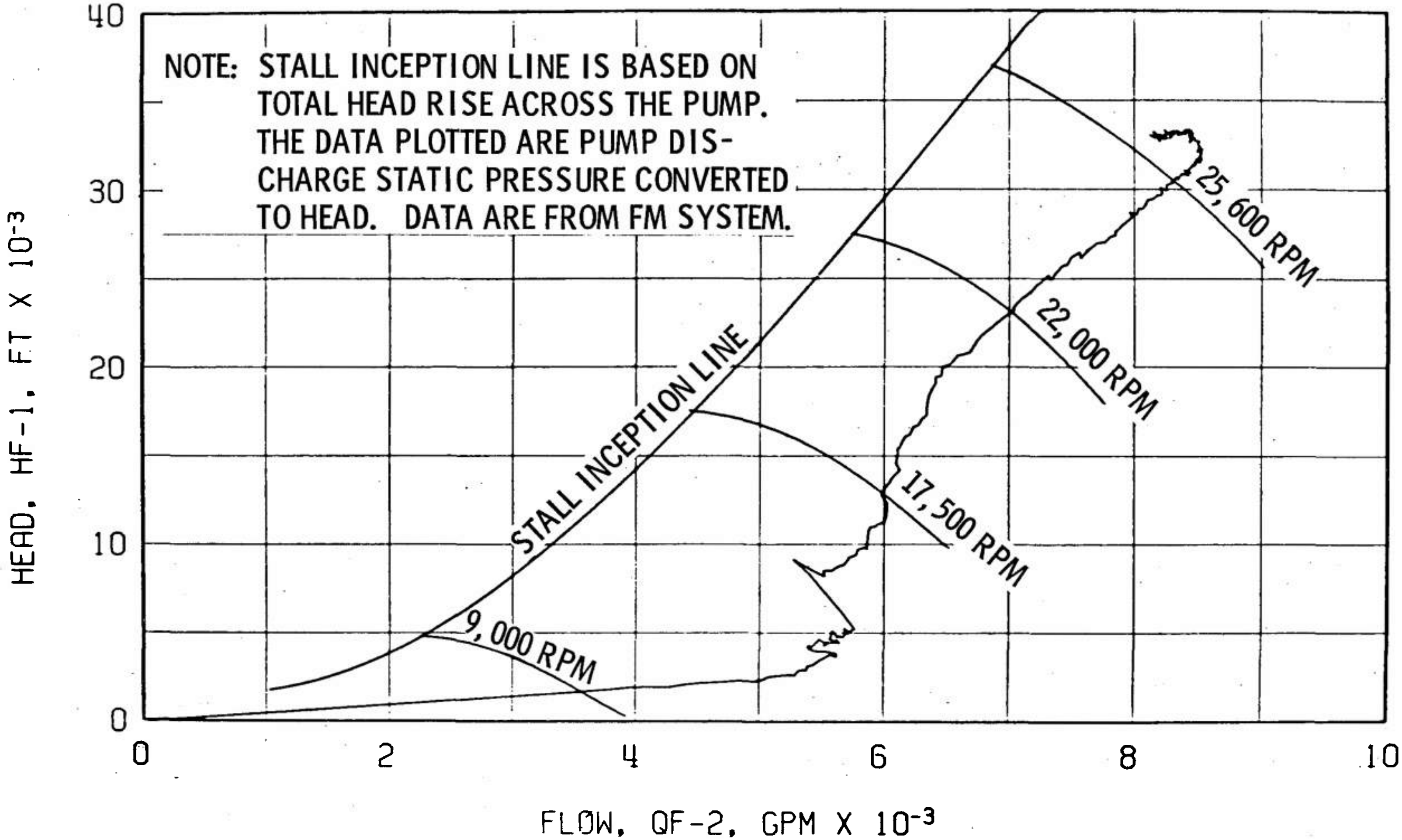
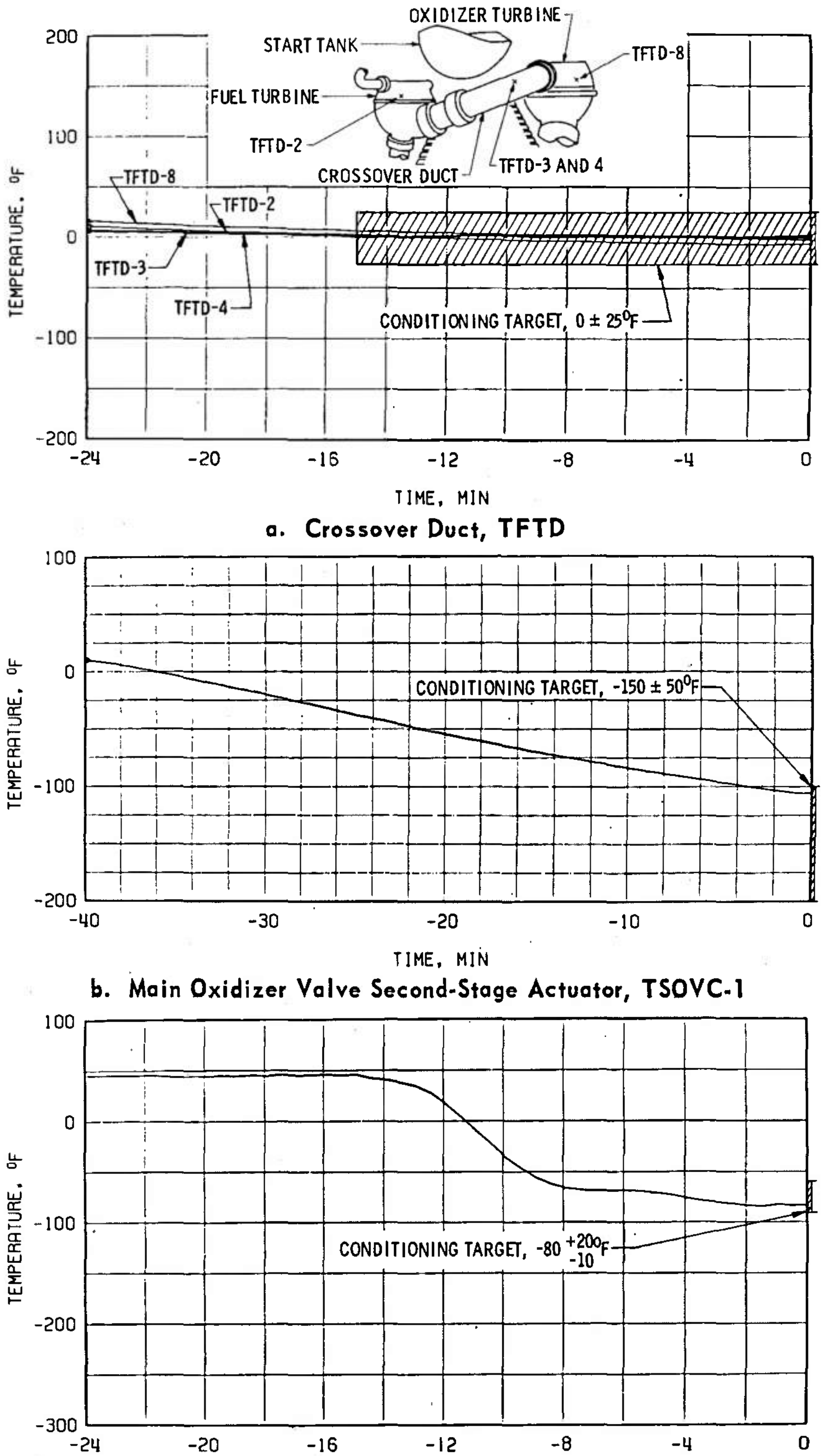


Fig. 51 Fuel Pump Start Transient Performance, Firing 40D

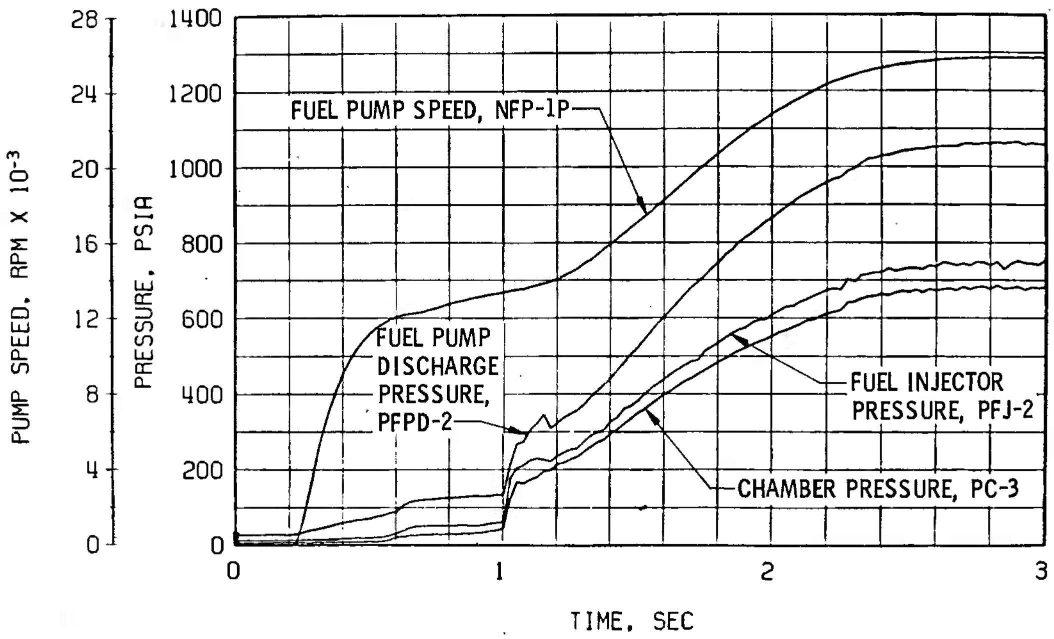


a. Crossover Duct, TFTD

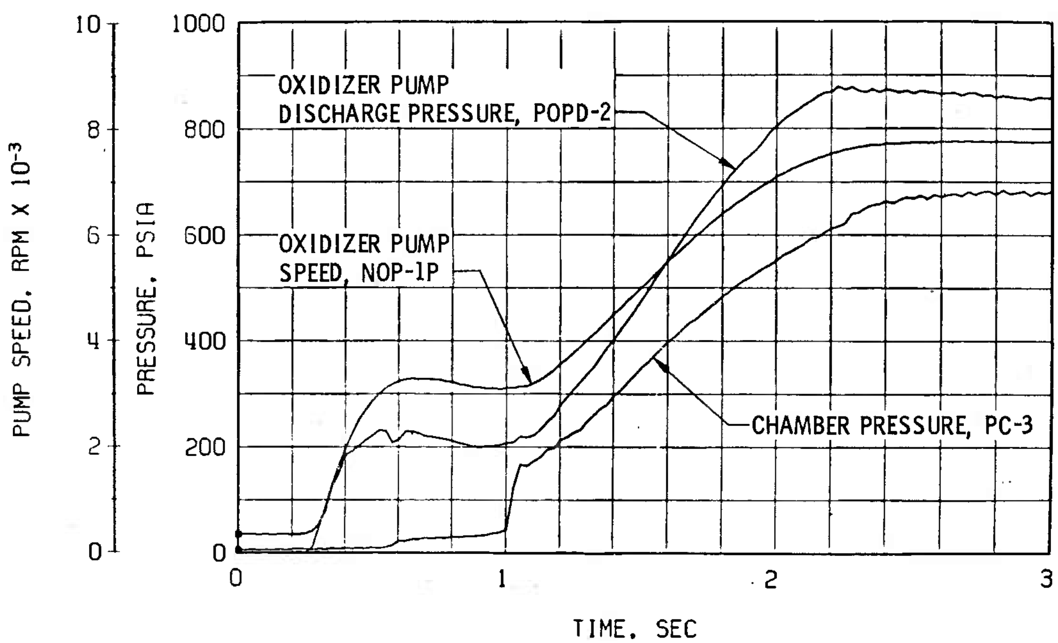
b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

c. Thrust Chamber Throat, TTC-1P

Fig. 52 Thermal Conditioning History of Engine Components, Firing 41A

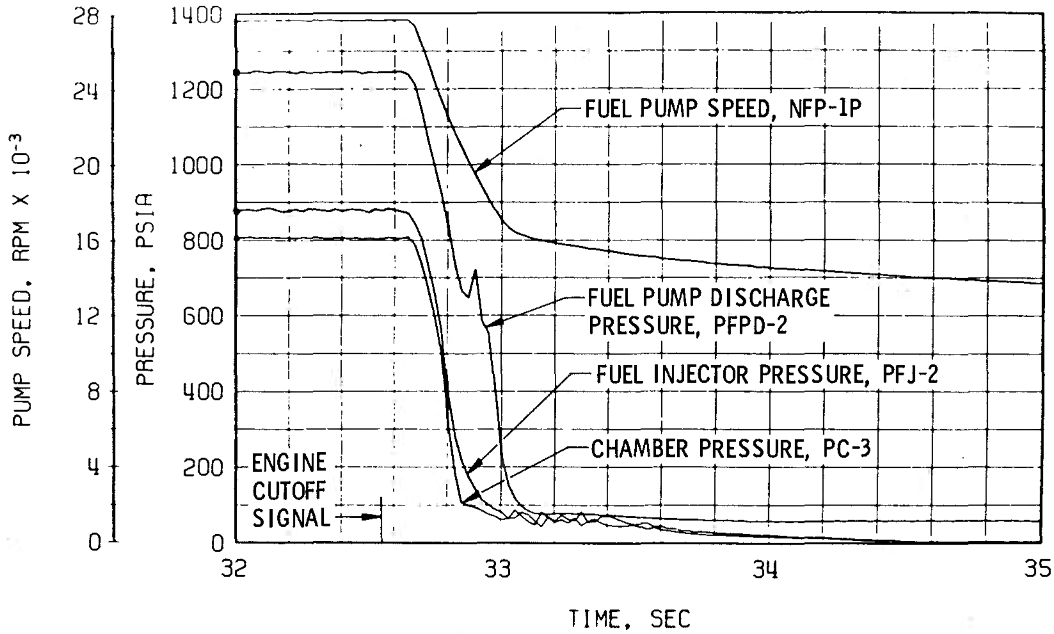


a. Thrust Chamber Fuel System, Start

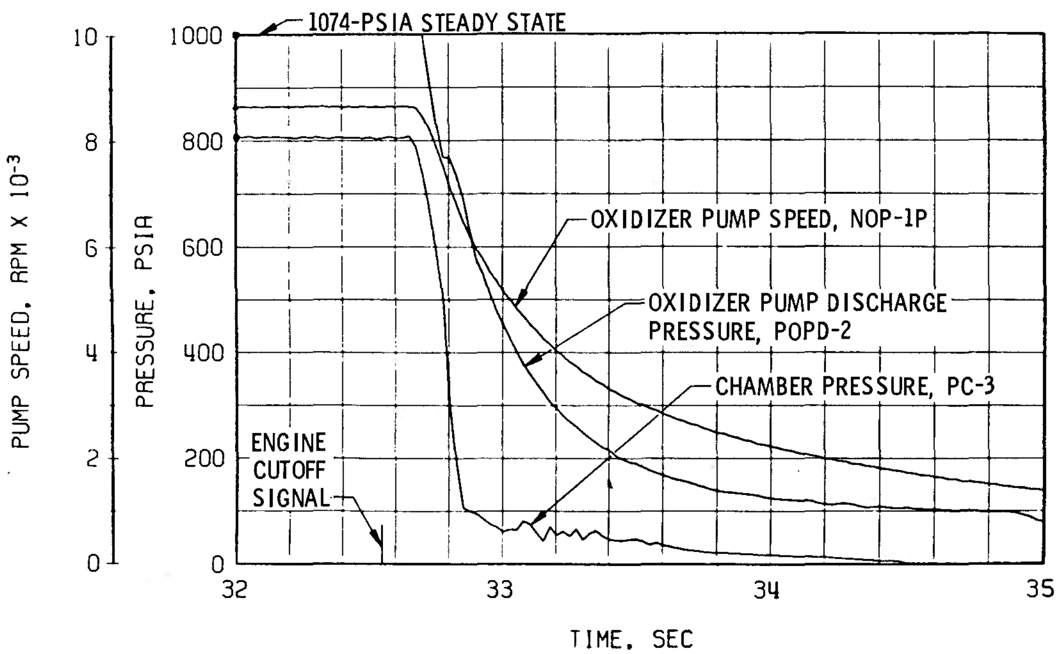


b. Thrust Chamber Oxidizer System, Start

Fig. 53 Engine Transient Operation, Firing 41A

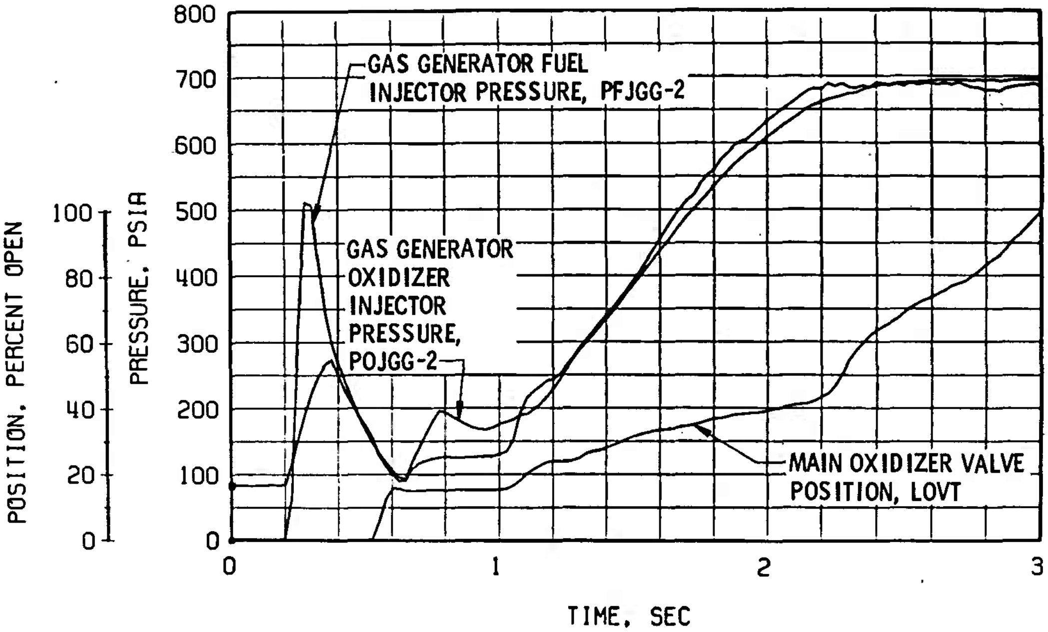


c. **Thrust Chamber Fuel System, Shutdown**

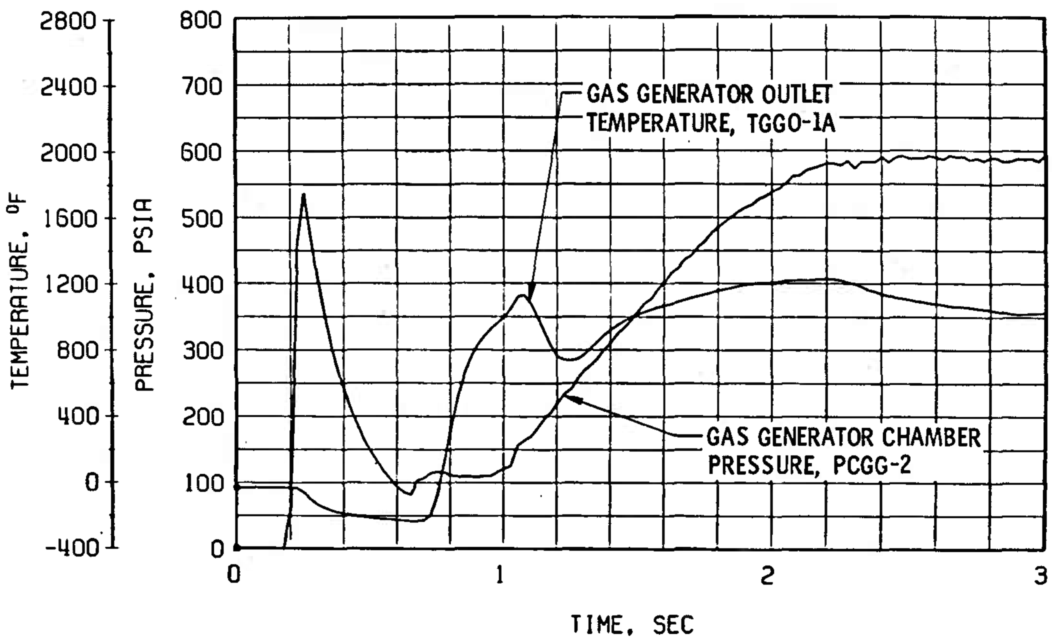


d. **Thrust Chamber Oxidizer System, Shutdown**

Fig. 53 Continued

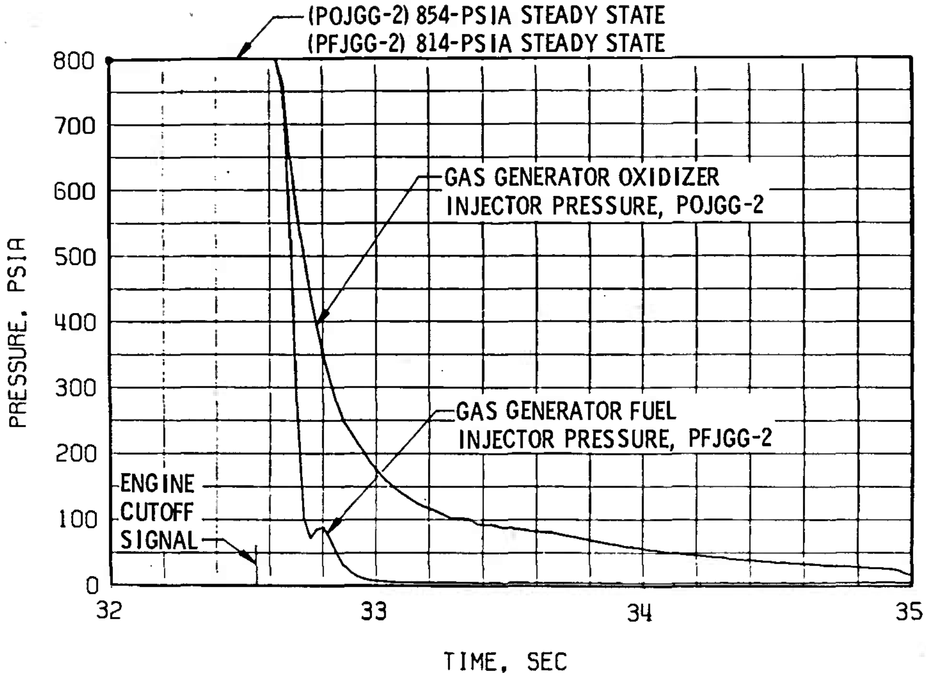


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

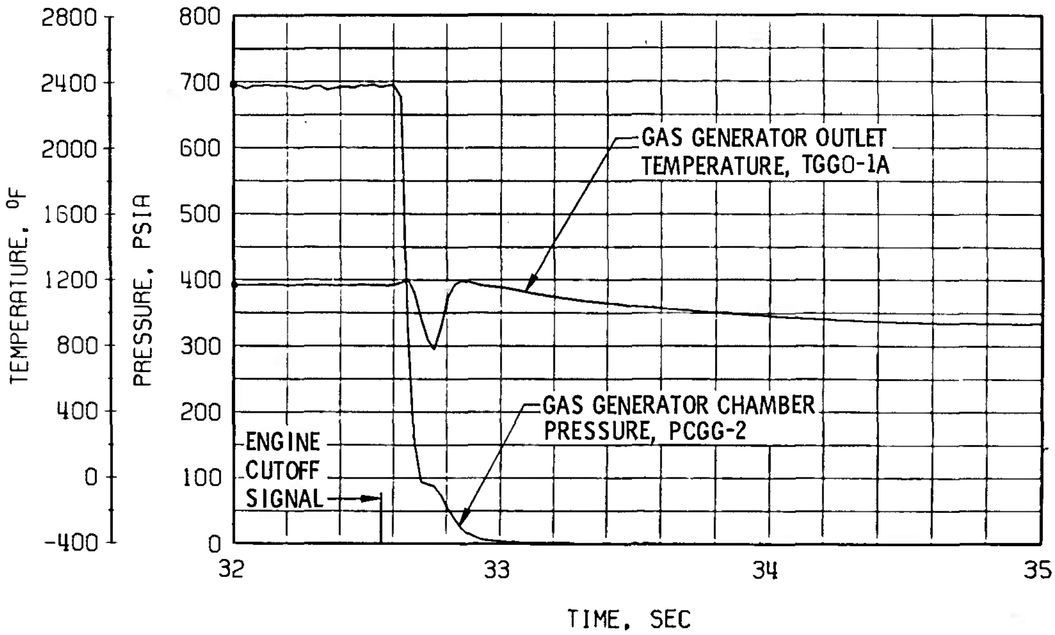


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 53 Continued

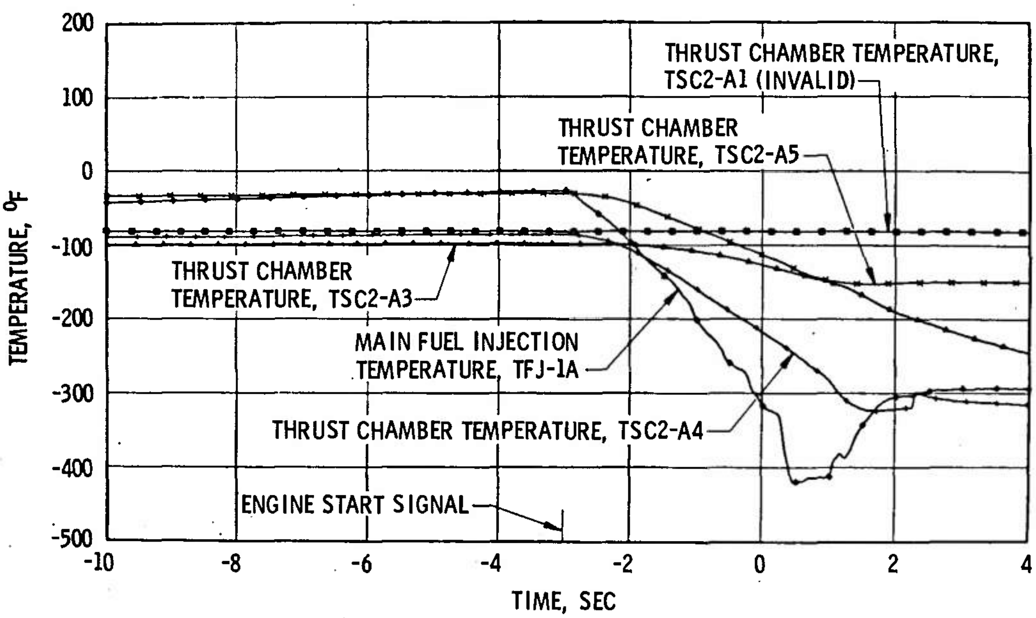


g. Gas Generator Injector Pressures, Shutdown

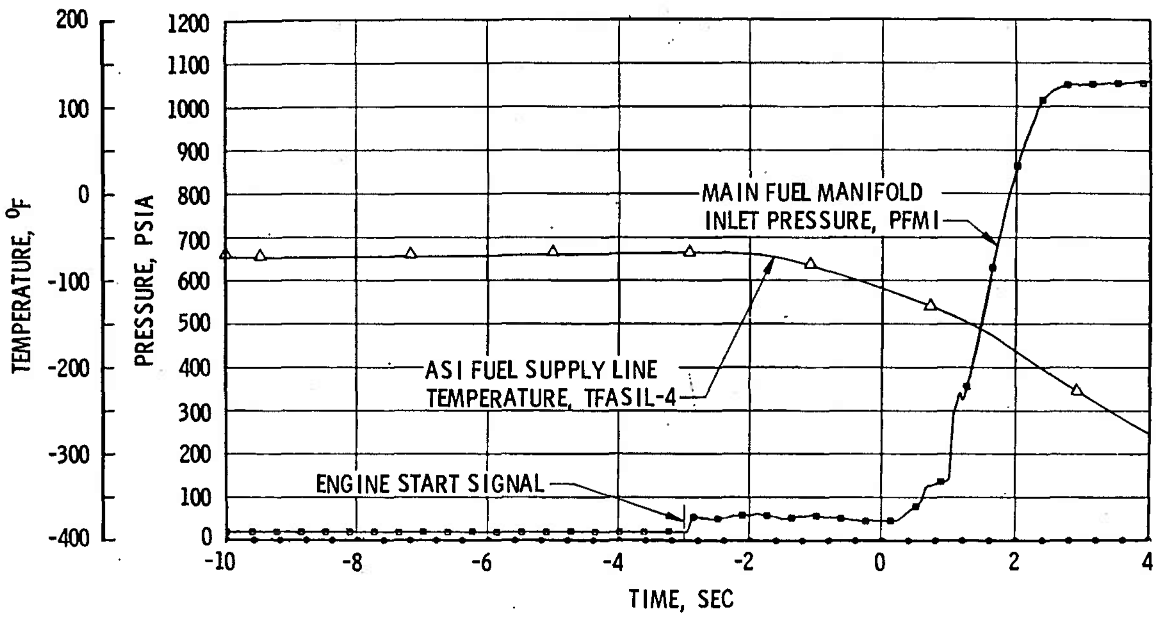


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 53 Continued

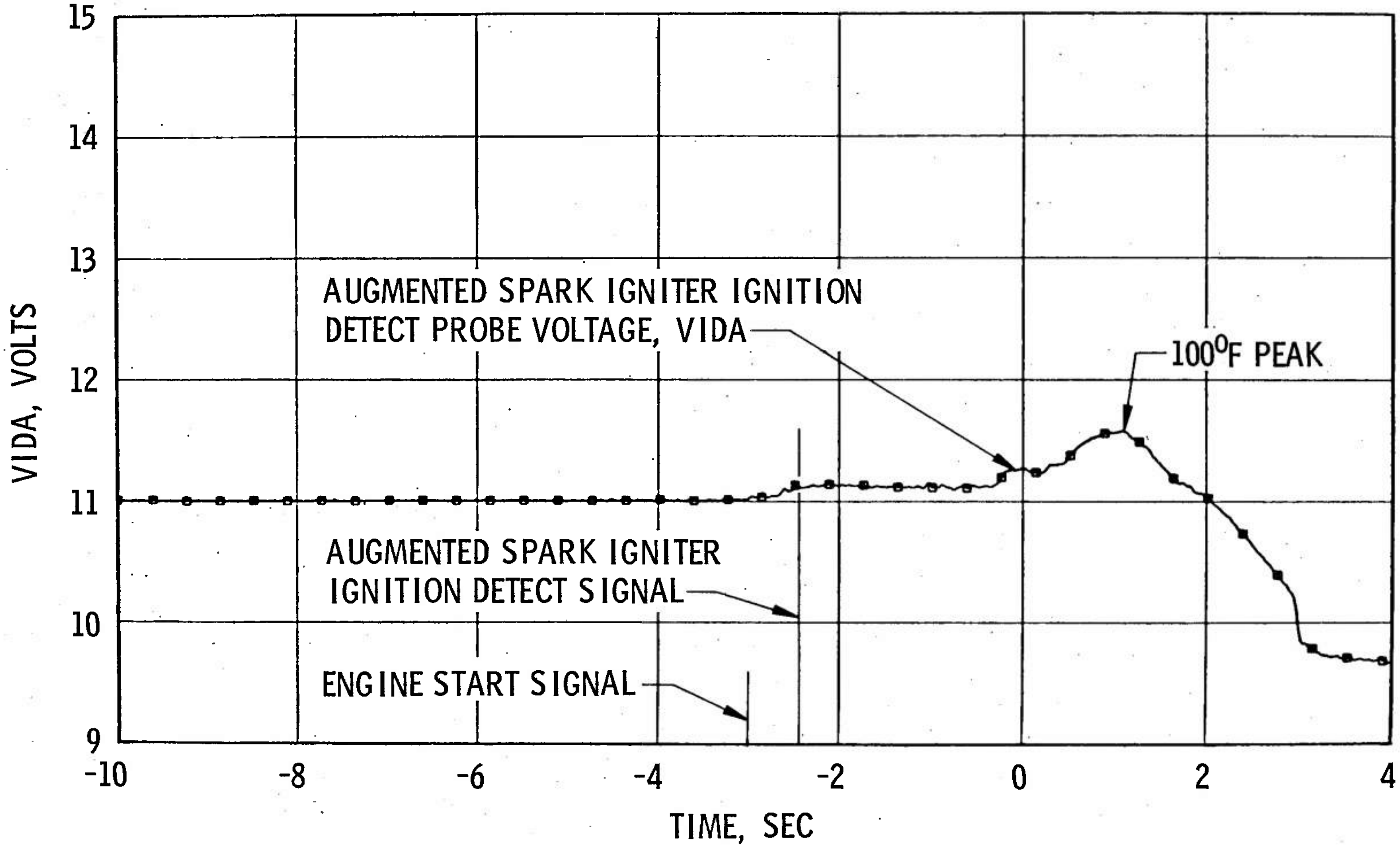


i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Pressure and Temperature Transient, Start

Fig. 53 Continued



k. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 53 Concluded

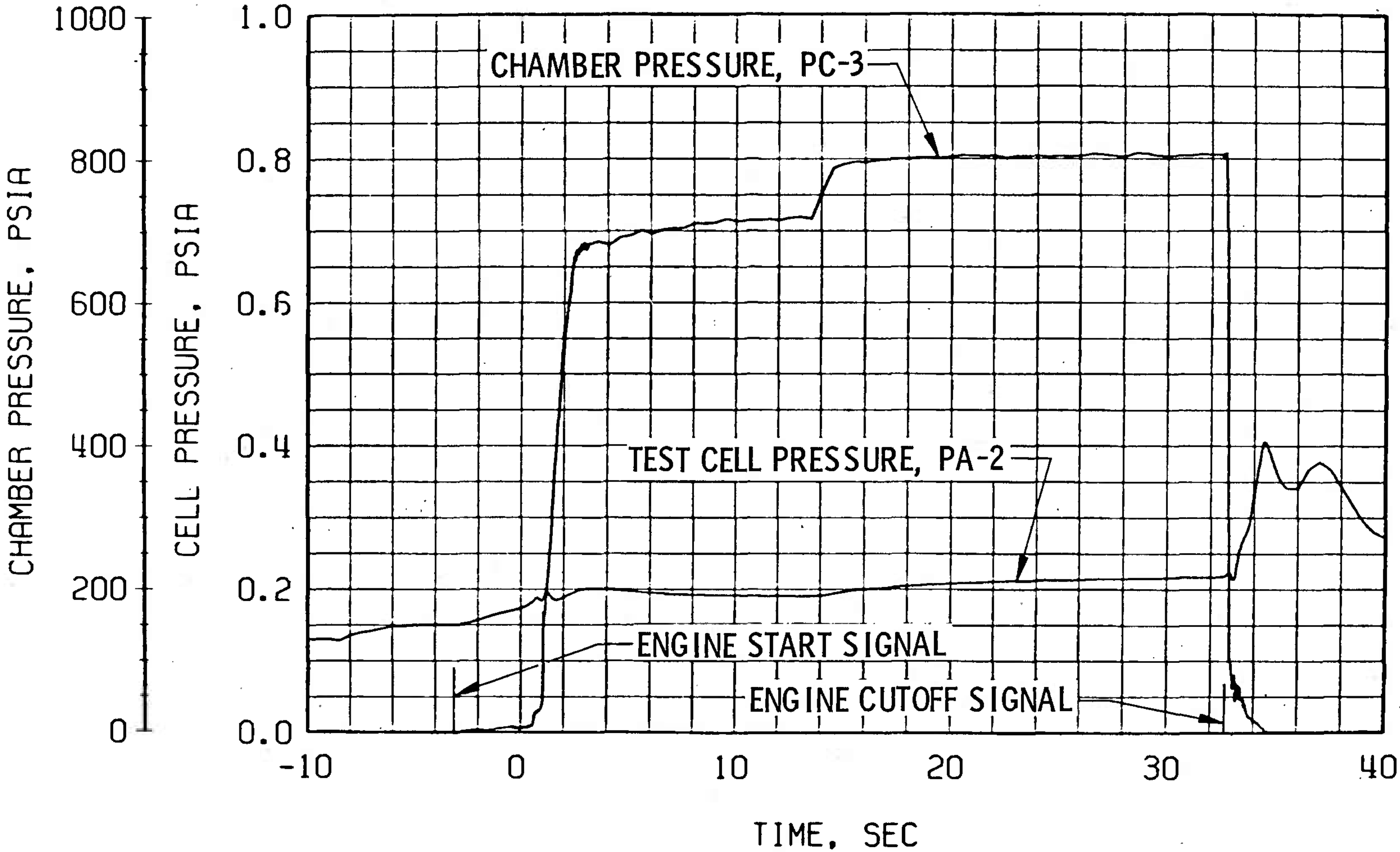


Fig. 54 Engine Ambient and Combustion Chamber Pressures, Firing 41A

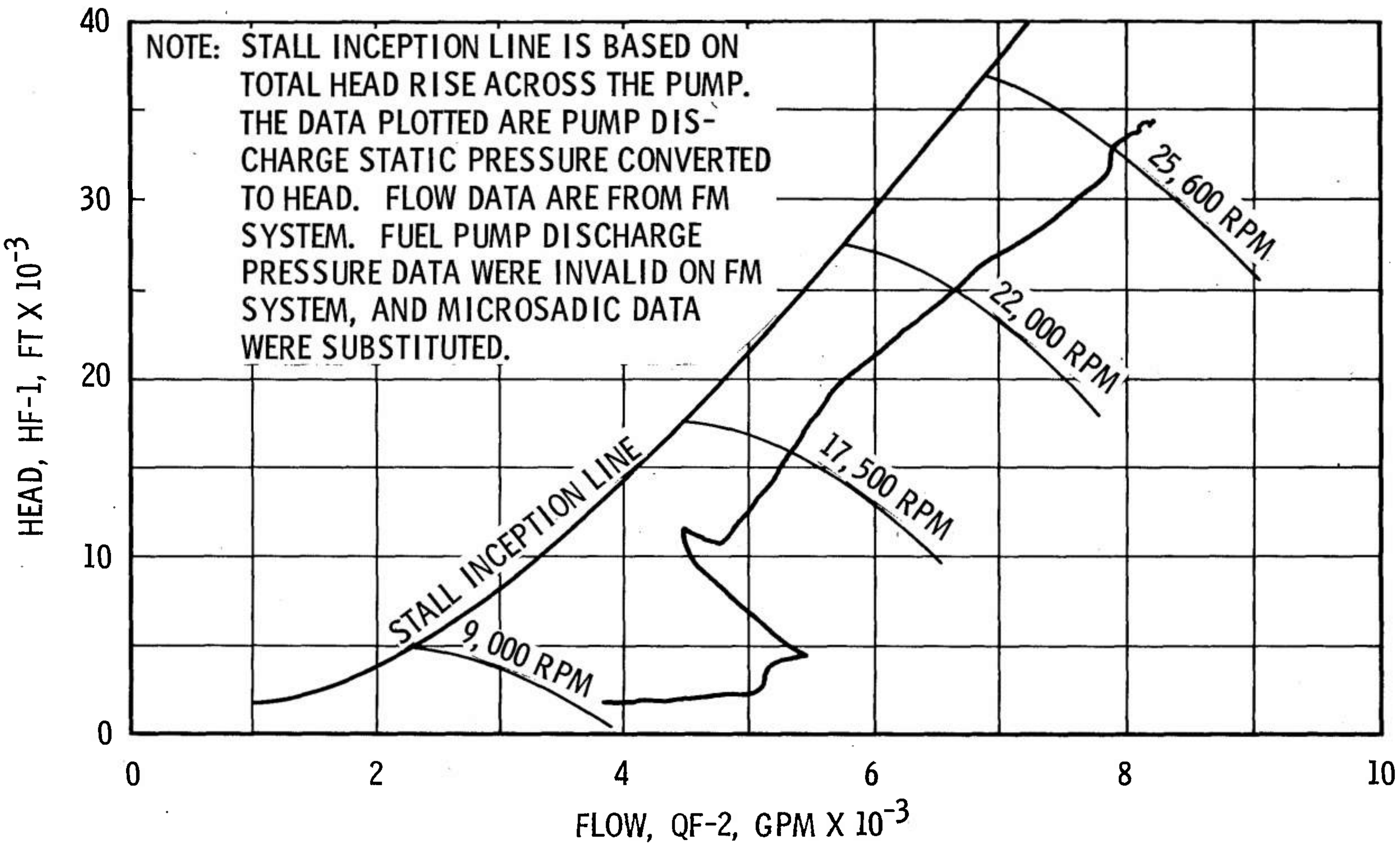
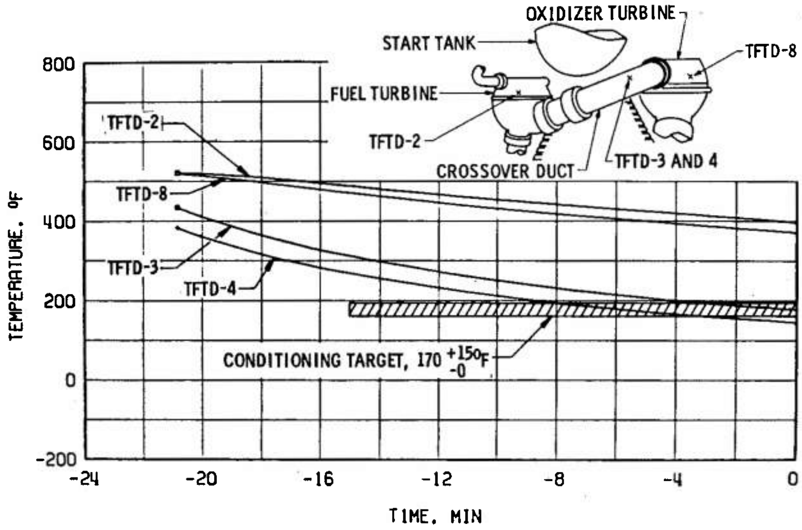
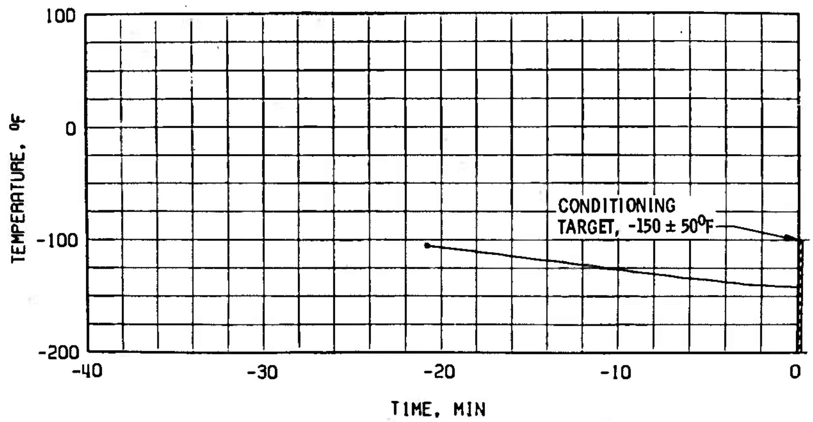


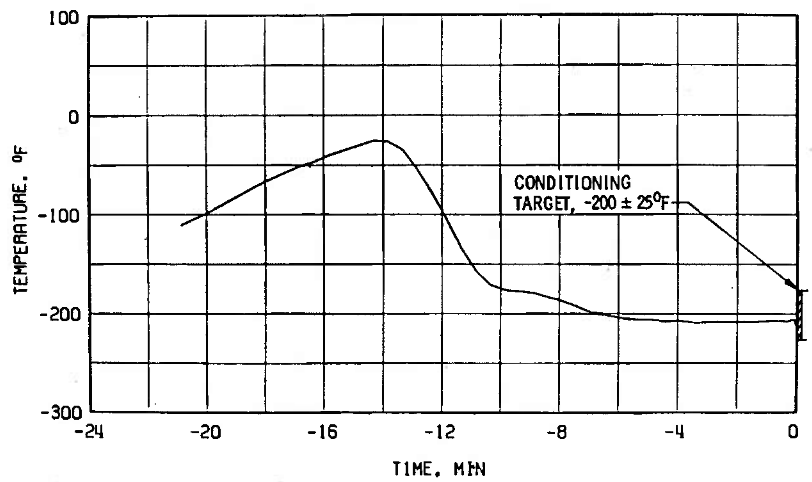
Fig. 55 Fuel Pump Start Transient Performance, Firing 41A



a. Crossover Duct, TFTD

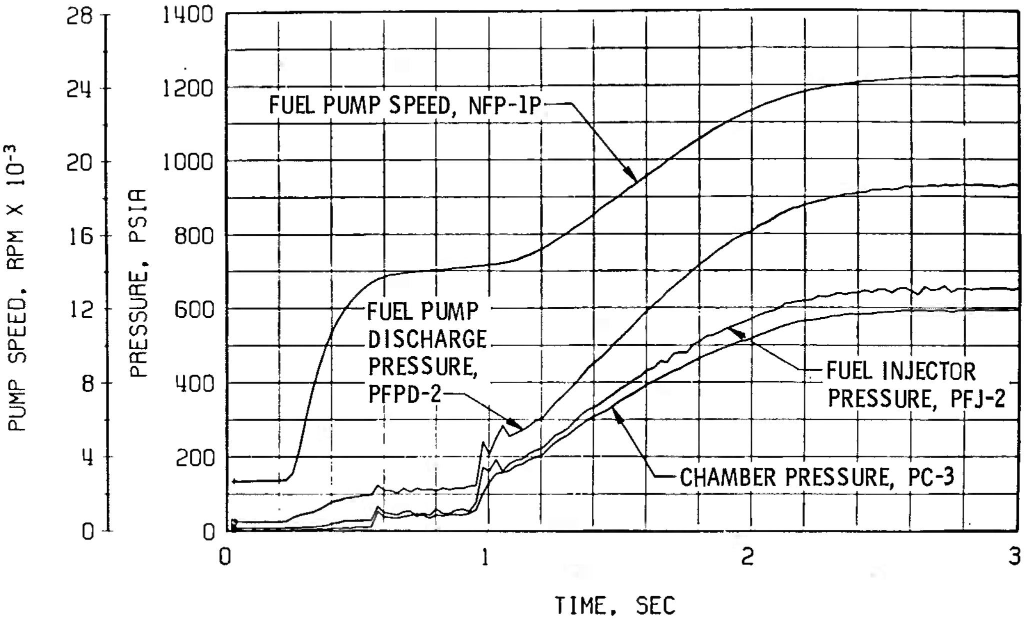


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

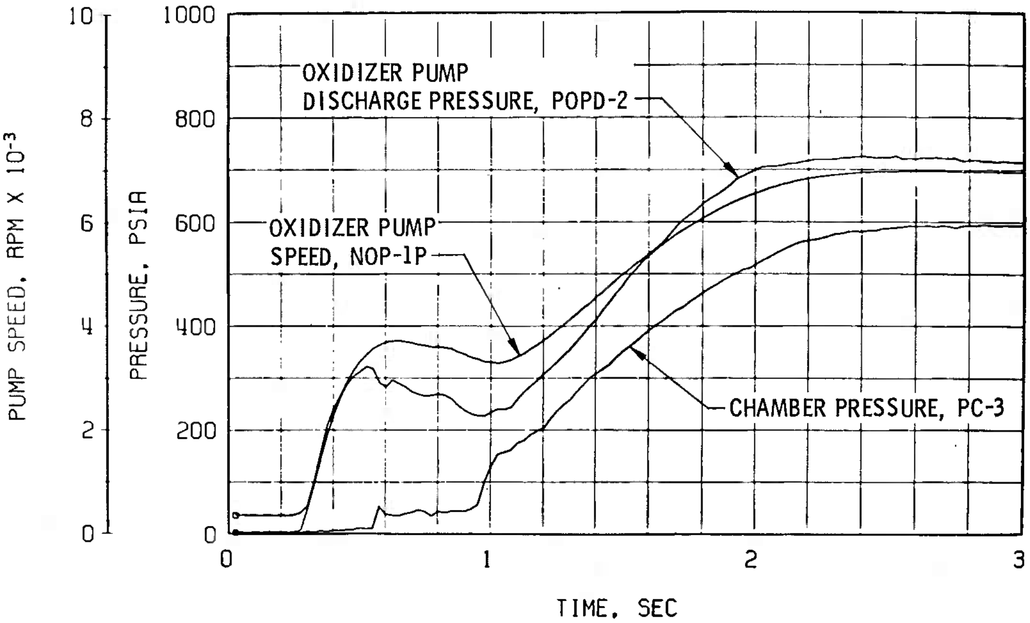


c. Thrust Chamber Throat, TTC-1P

Fig. 56 Thermal Conditioning History of Engine Components, Firing 41B

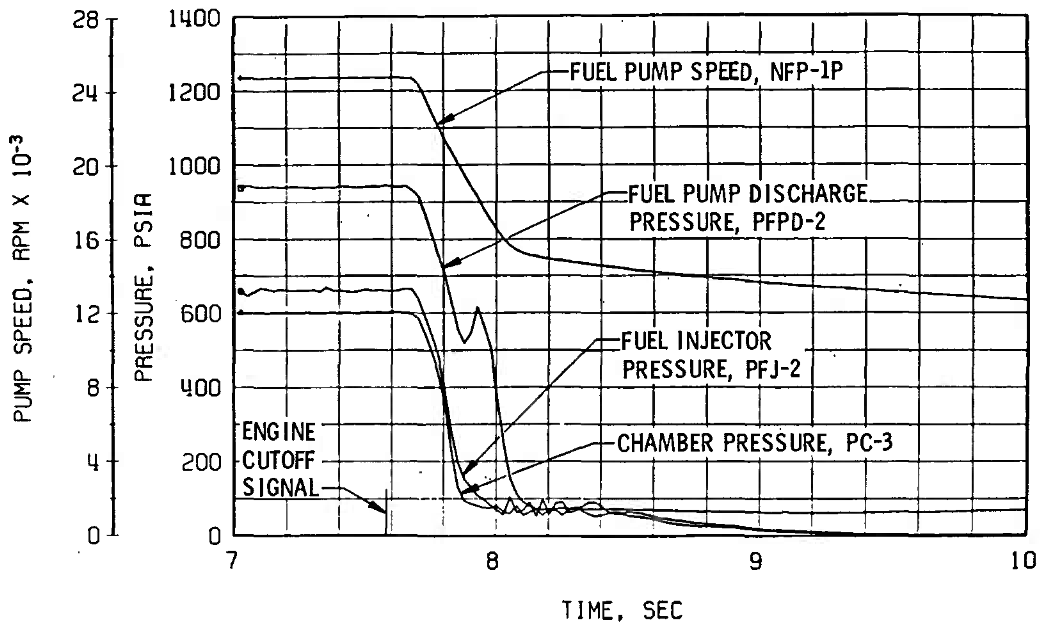


a. Thrust Chamber Fuel System, Start

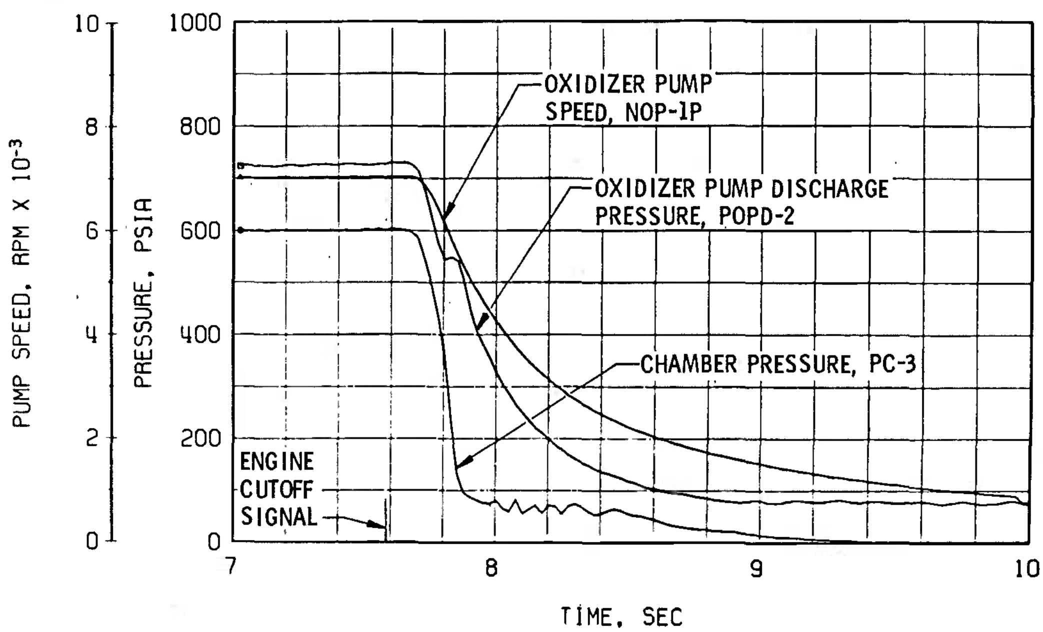


b. Thrust Chamber Oxidizer System, Start

Fig. 57 Engine Transient Operation, Firing 41B

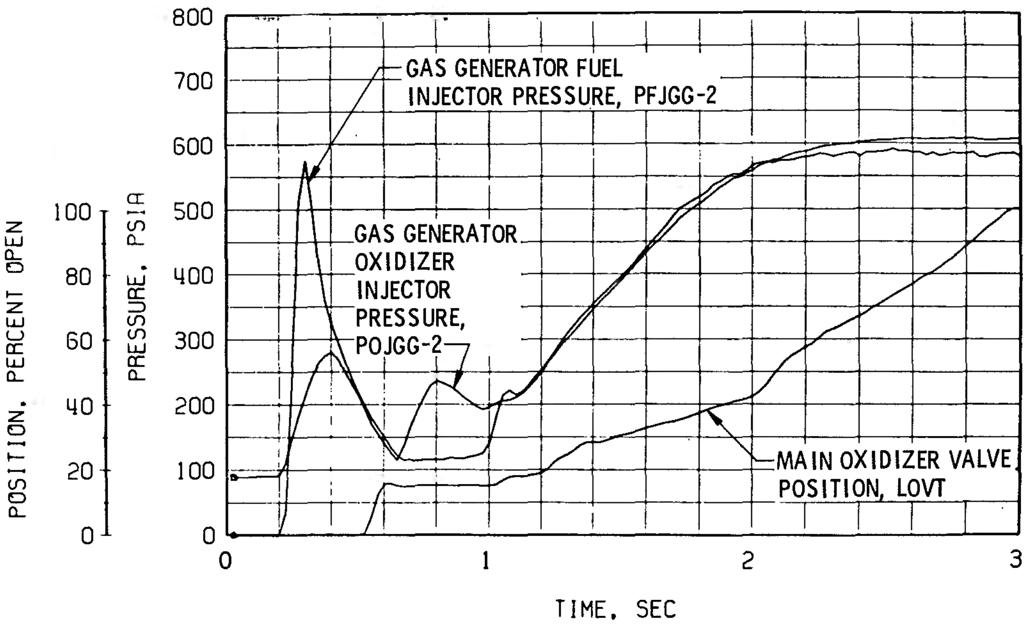


c. Thrust Chamber Fuel System, Shutdown

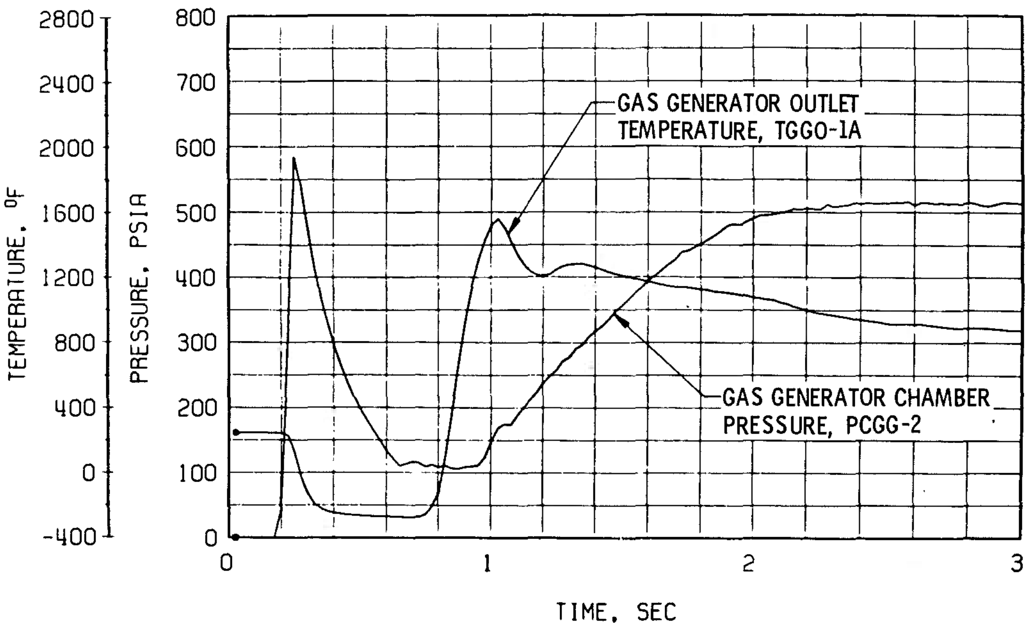


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 57 Continued

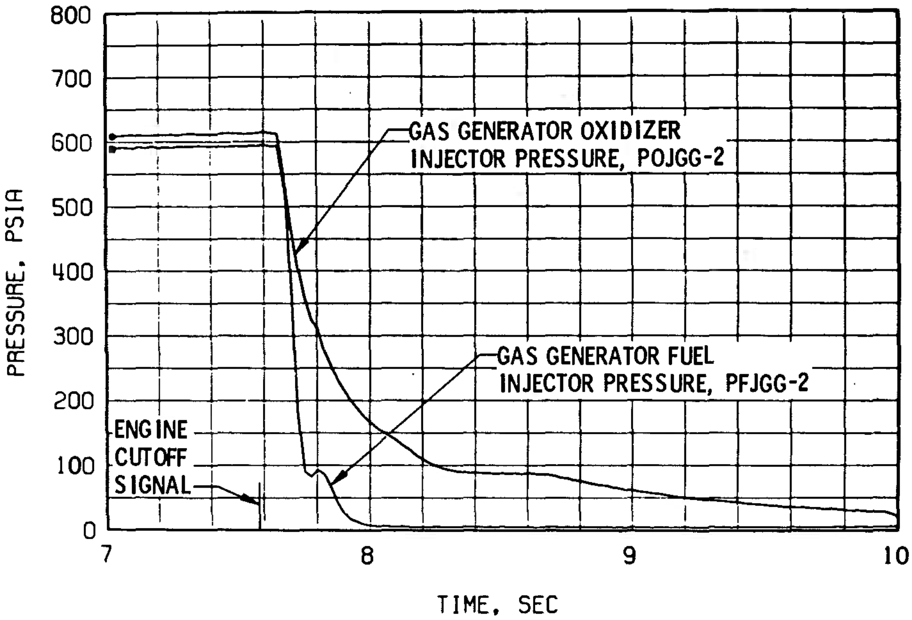


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

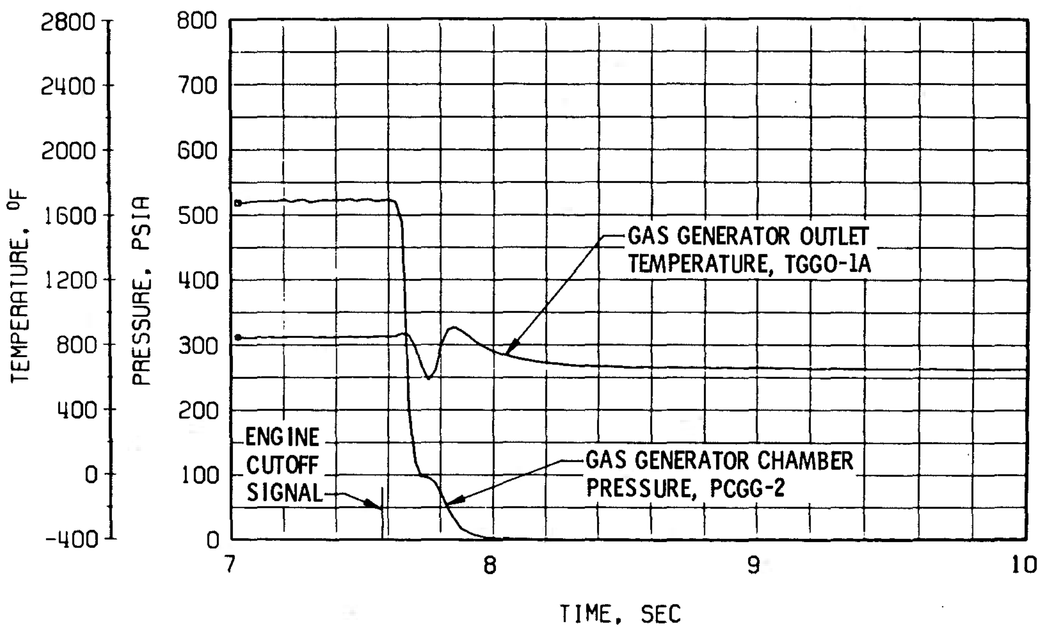


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 57 Continued

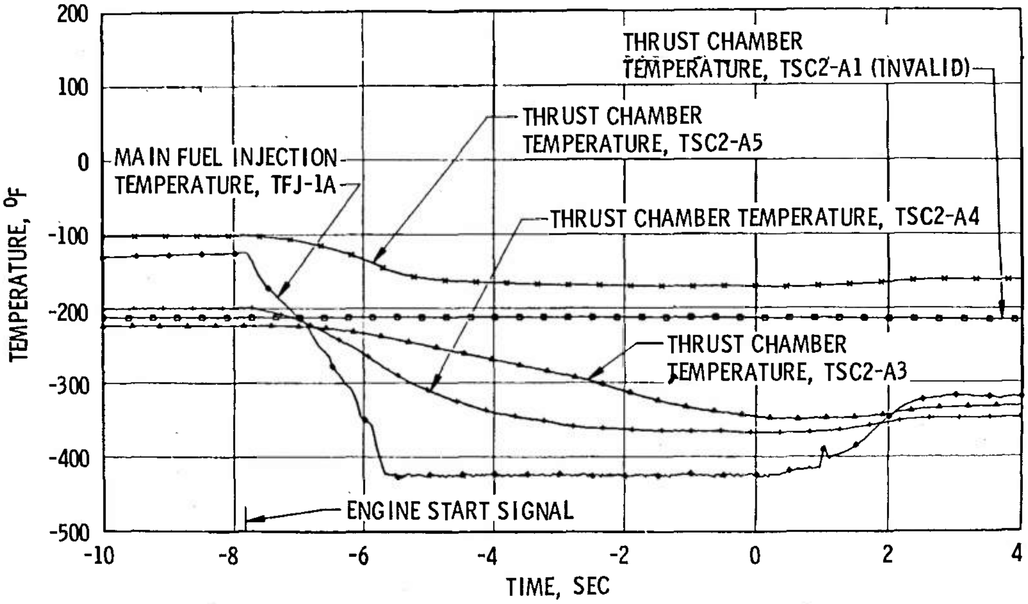


g. Gas Generator Injector Pressures, Shutdown

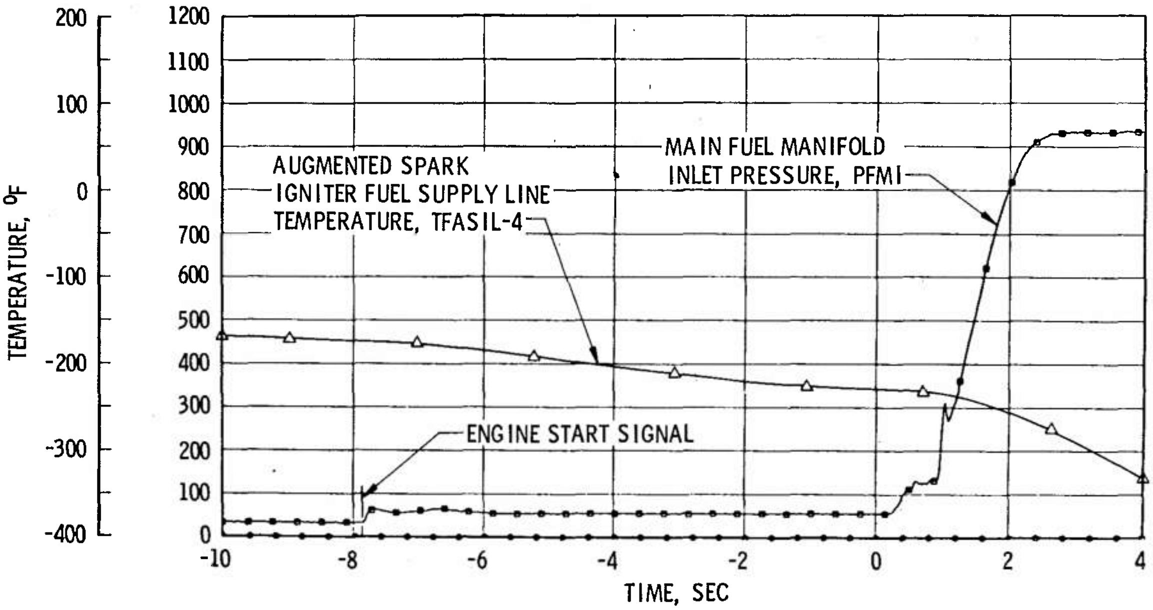


h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 57 Continued

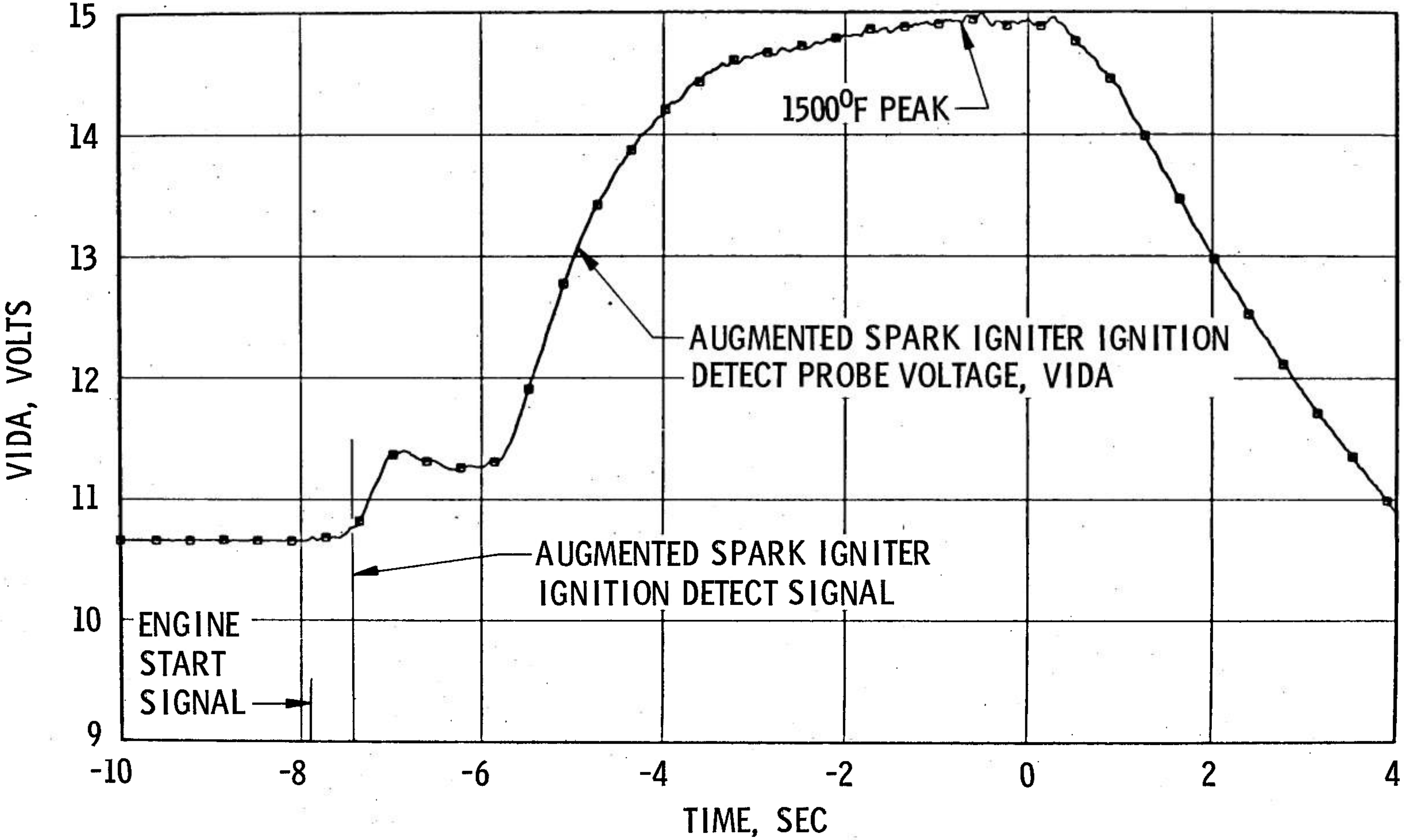


i. Thrust Chamber Temperature Transient, Start



j. Augmented Spark Igniter Fuel Supply Line Pressure and Temperature Transient, Start

Fig. 57 Continued



k. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 57 Concluded

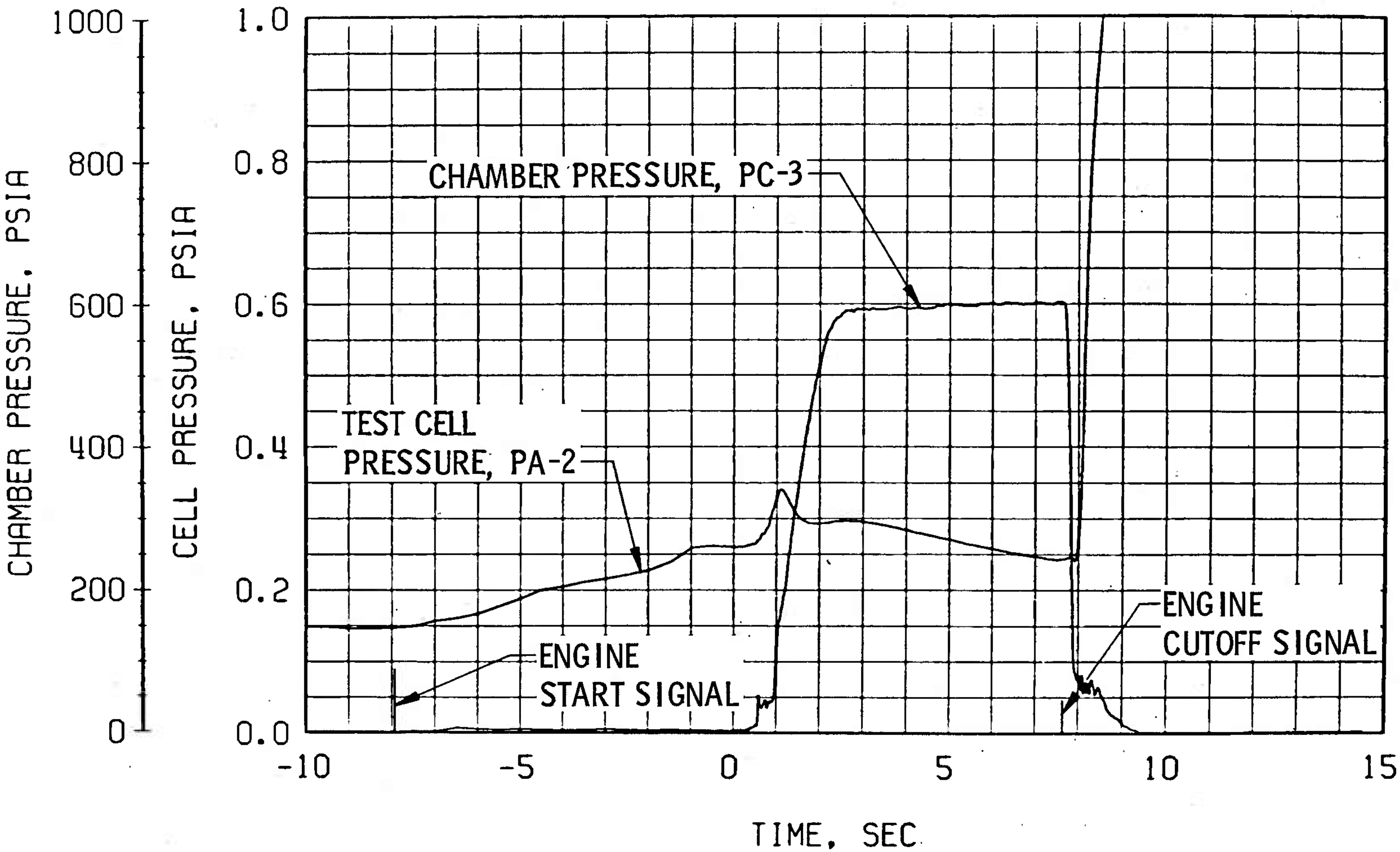


Fig. 58 Engine Ambient and Combustion Chamber Pressures, Firing 41B

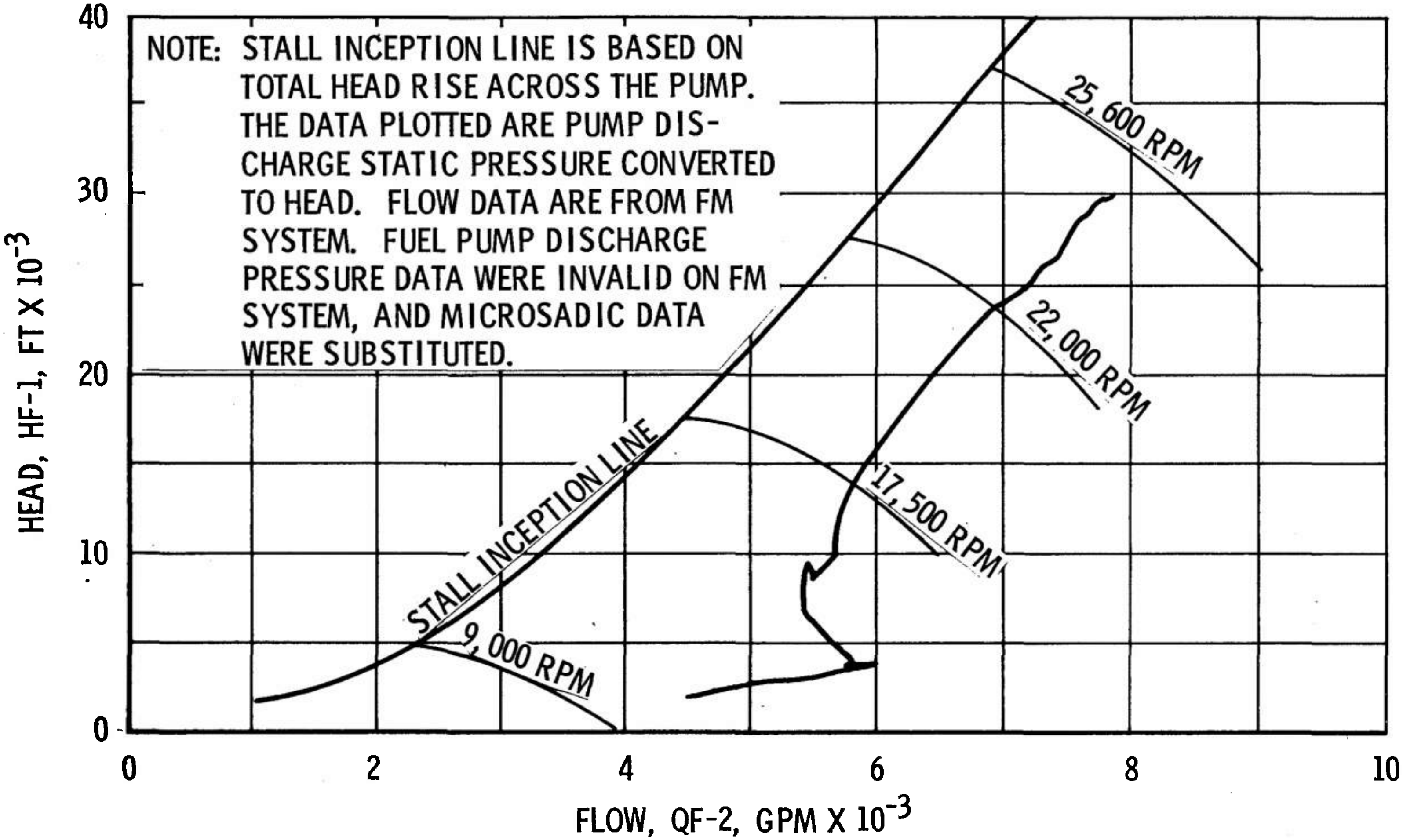
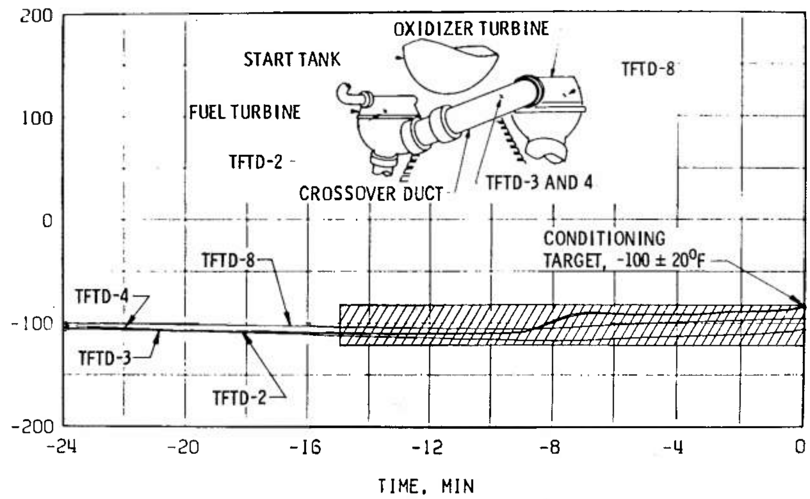
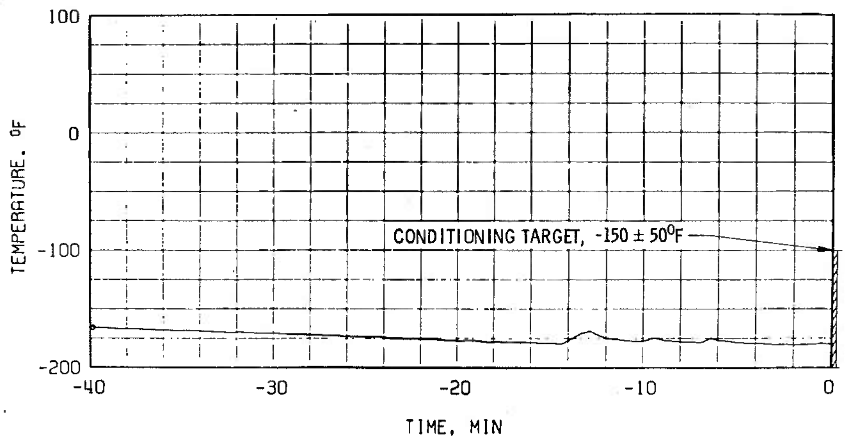


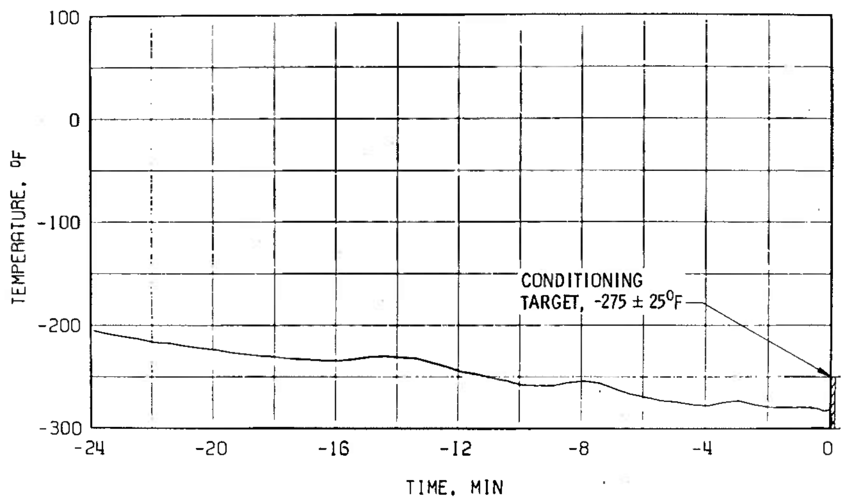
Fig. 59 Fuel Pump Start Transient Performance, Firing 41B



a. Crossover Duct, TFTD

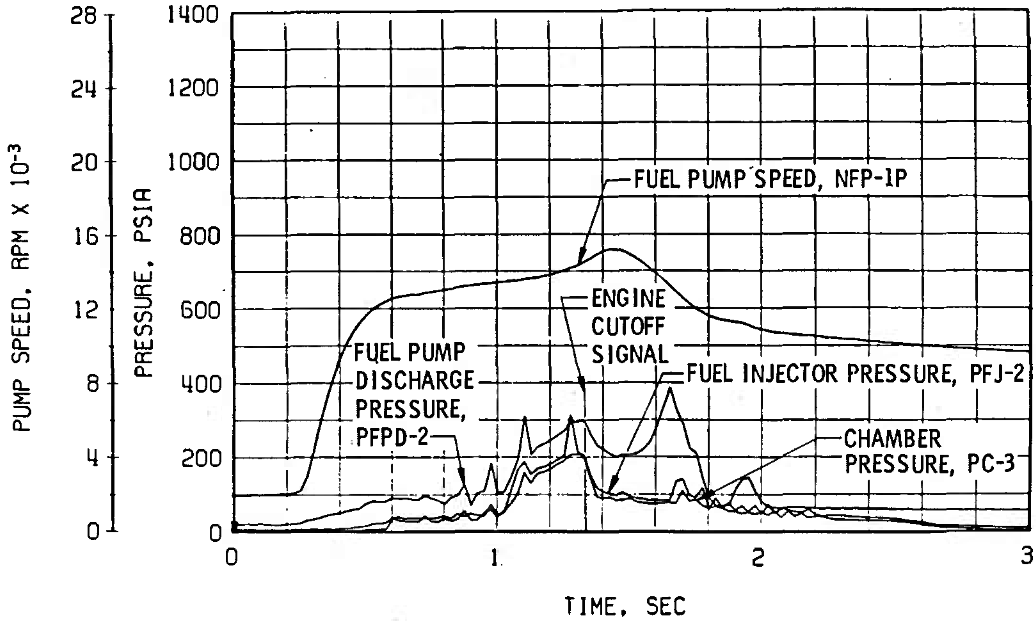


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

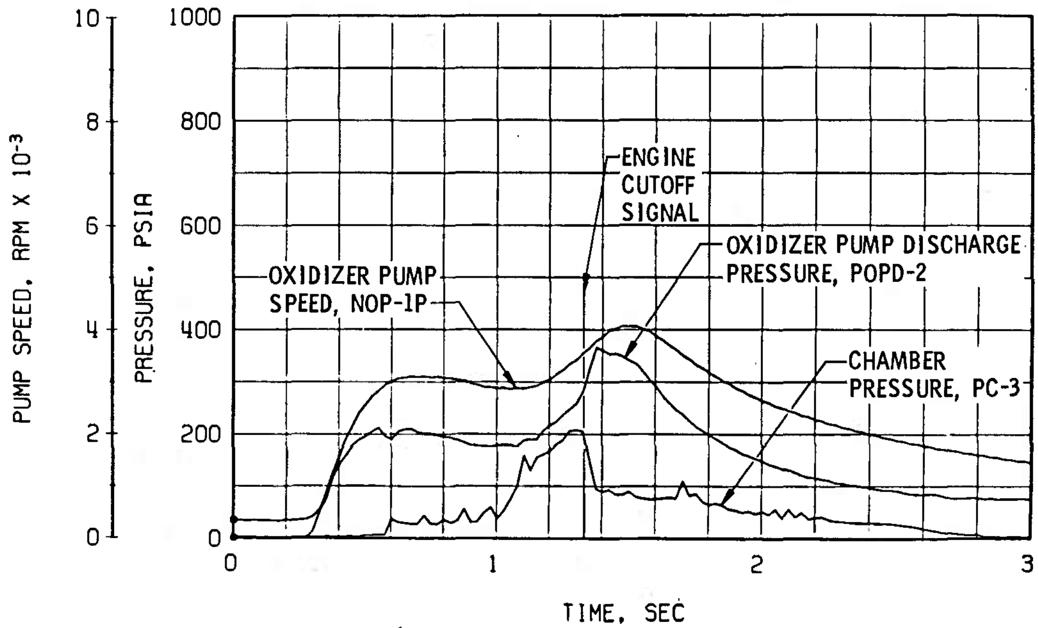


c. Thrust Chamber Throat, TTC-1P

Fig. 60 Thermal Conditioning History of Engine Components, Firing 41C

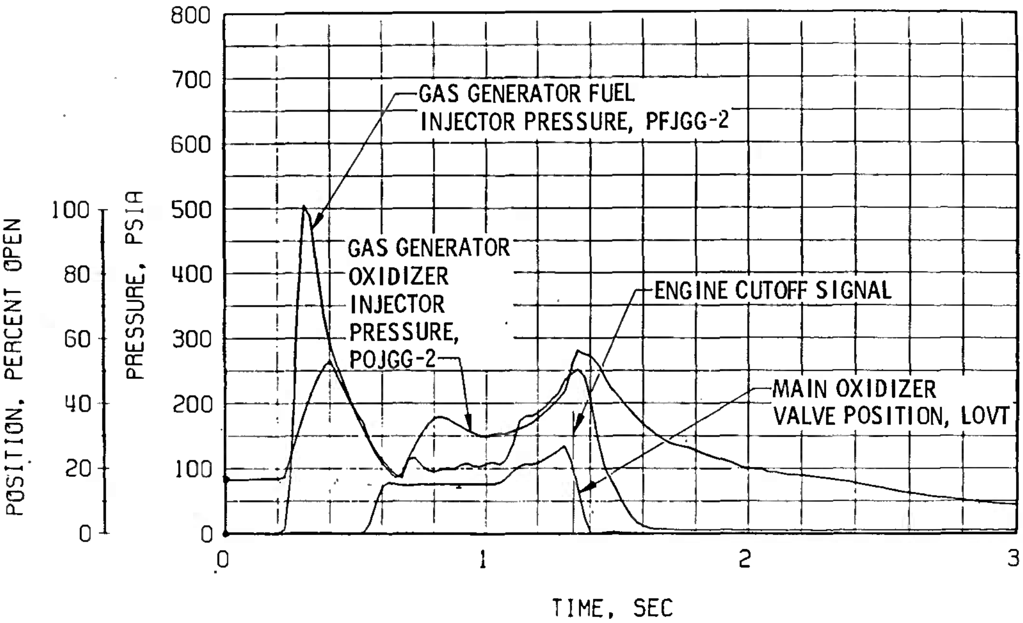


a. Thrust Chamber Fuel System

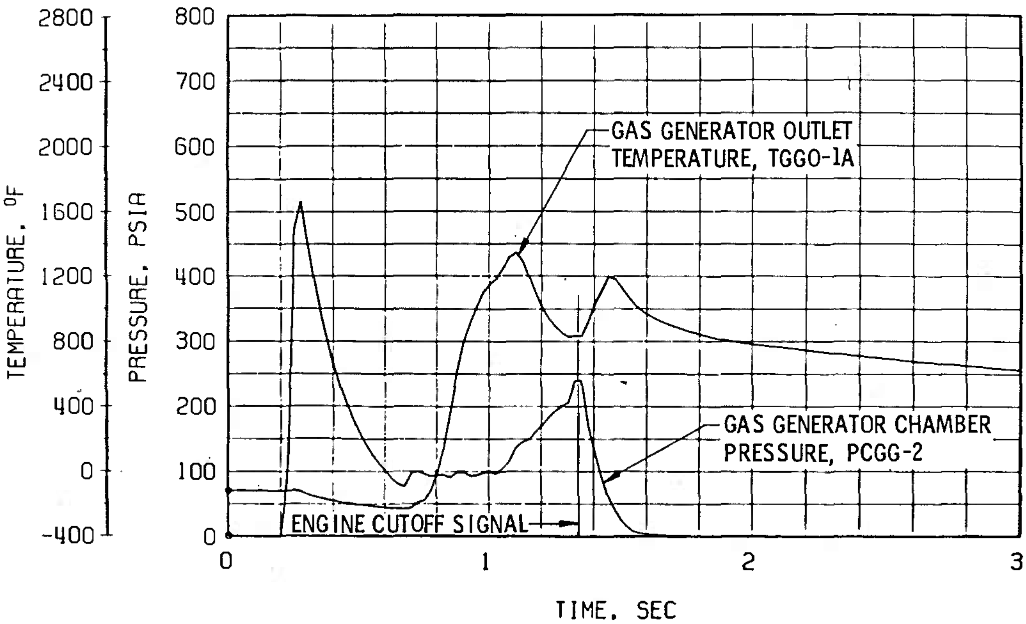


b. Thrust Chamber Oxidizer System

Fig. 61 Engine Transient Operation, Firing 41C

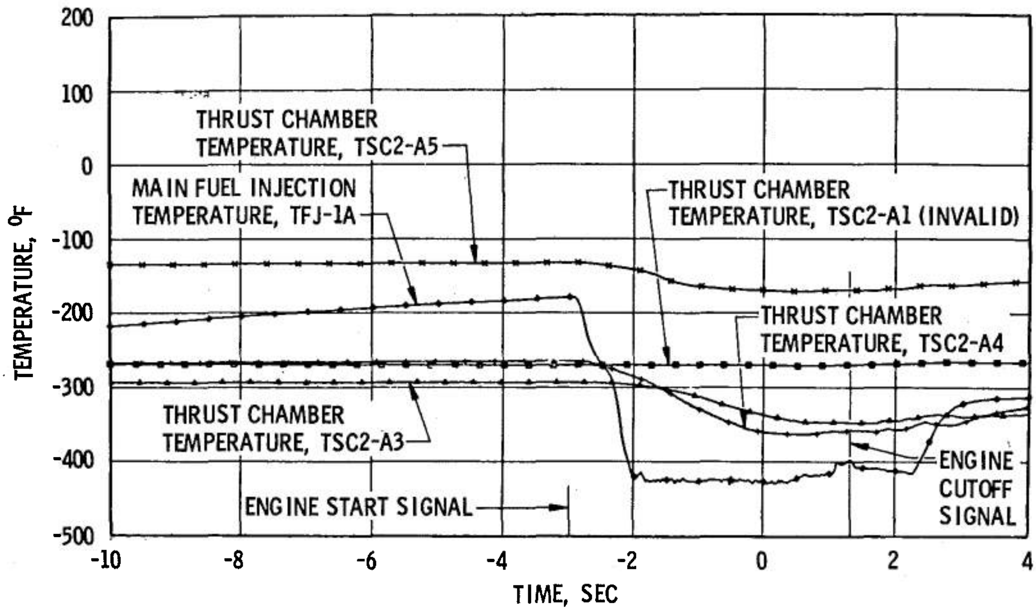


c. **Gas Generator Injector Pressures and Main Oxidizer Valve Position**

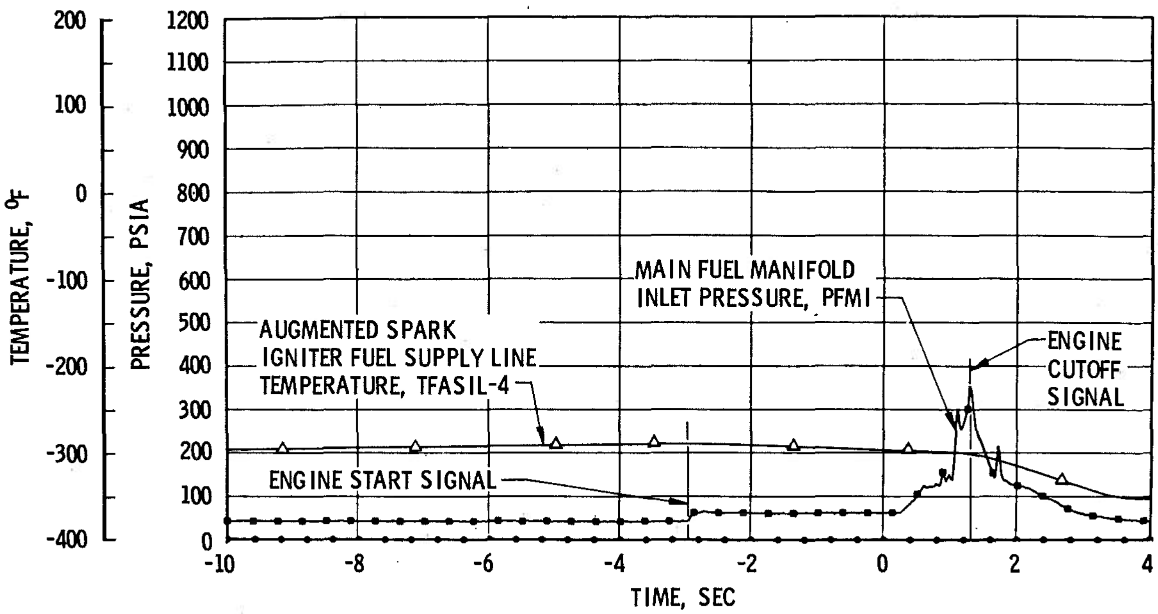


d. **Gas Generator Chamber Pressure and Temperature**

Fig. 61 Continued

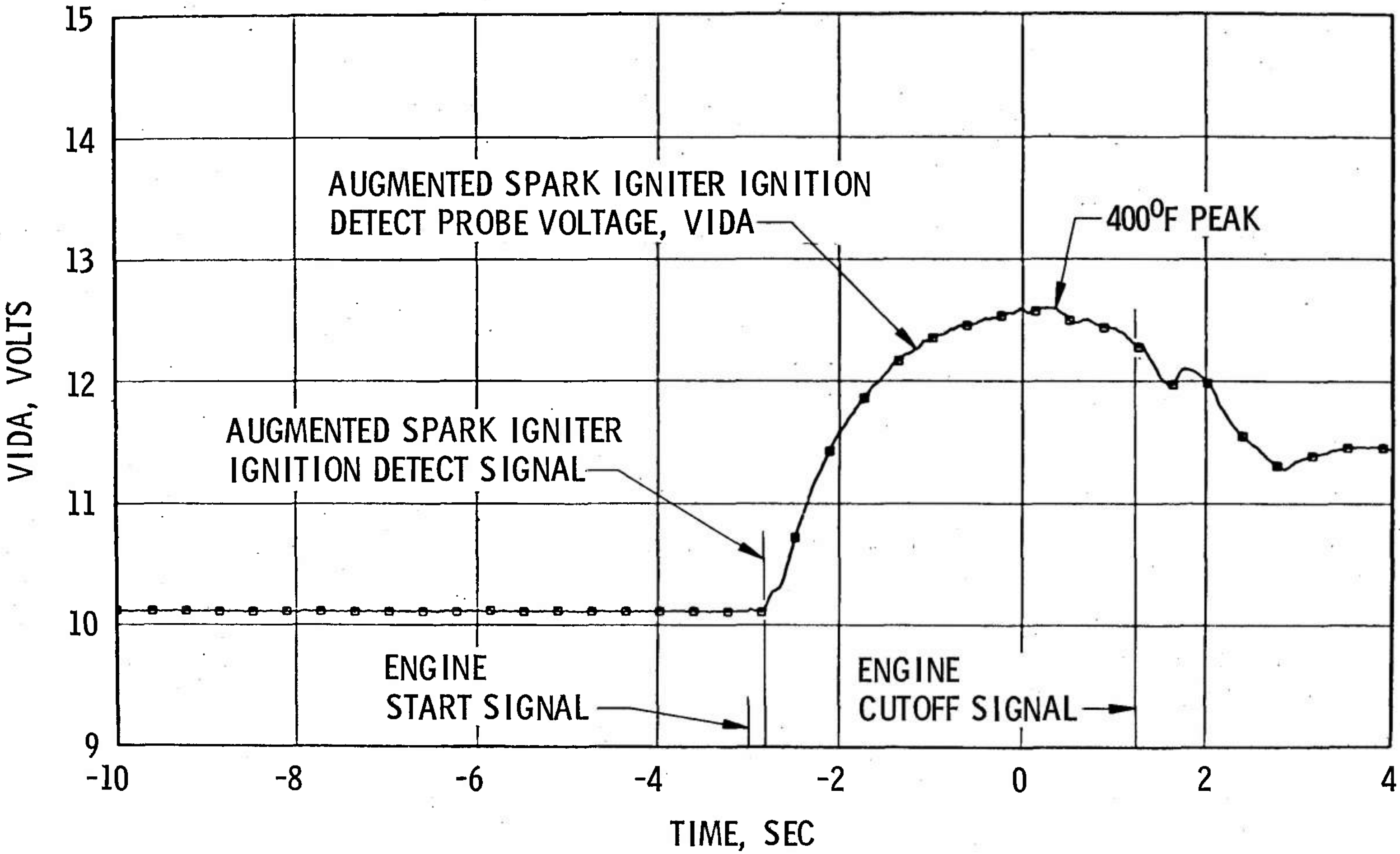


e. Thrust Chamber Temperature Transient



f. Augmented Spark Igniter Fuel Supply Line Pressure and Temperature Transient

Fig. 61 Continued



g. Augmented Spark Igniter Ignition Detect Probe Temperature Transient

Fig. 61 Concluded

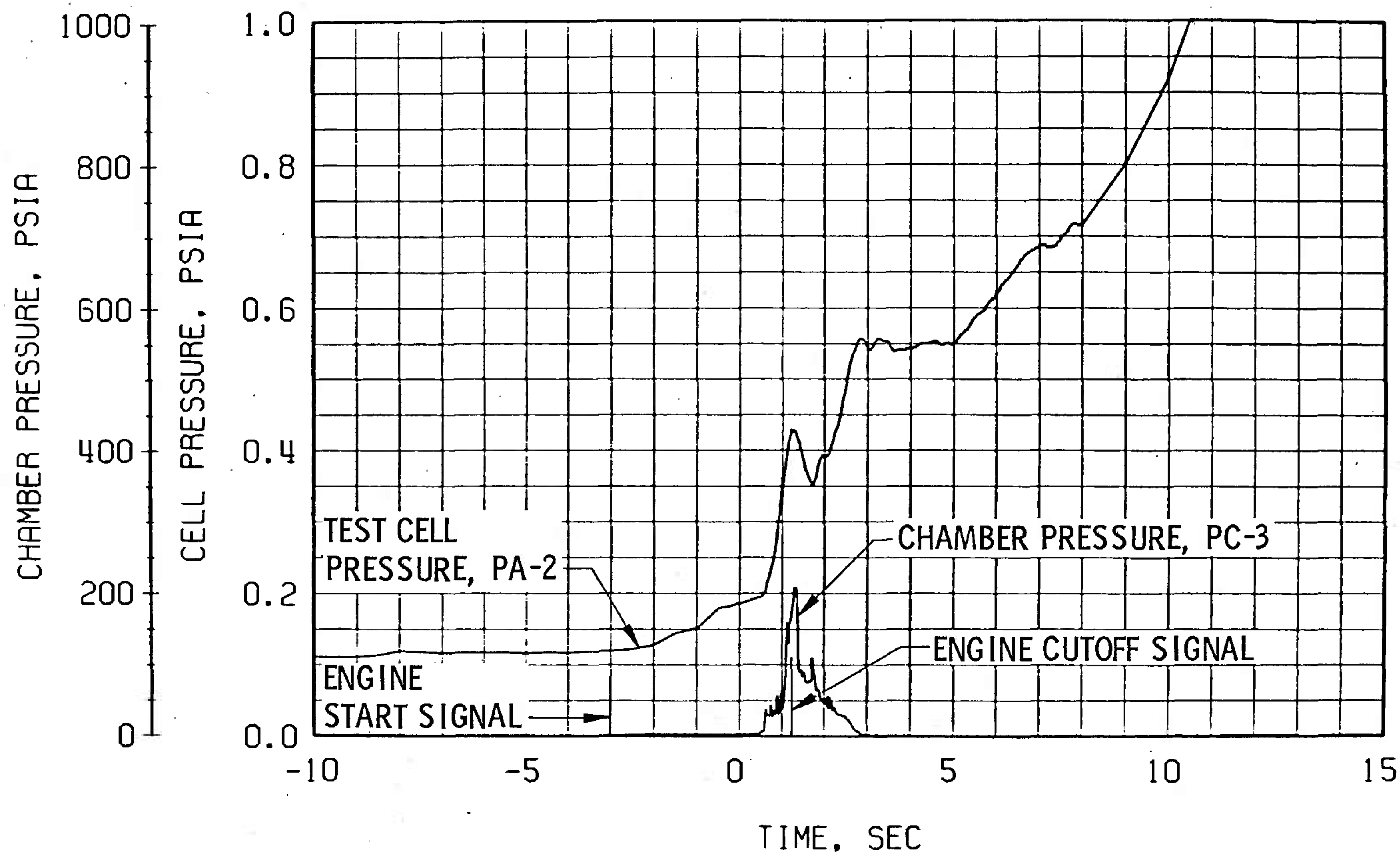


Fig. 62 Engine Ambient and Combustion Chamber Pressures, Firing 41C

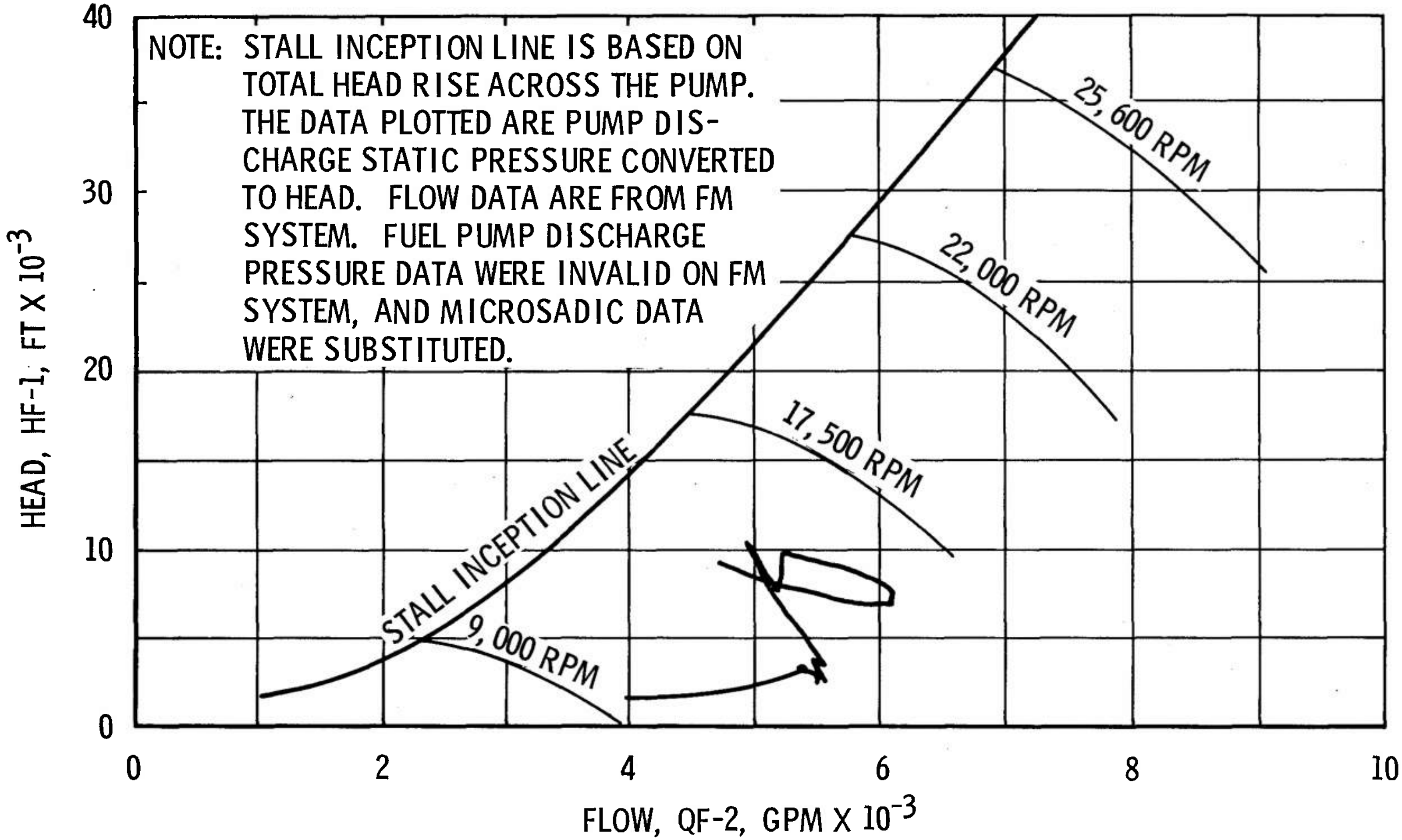
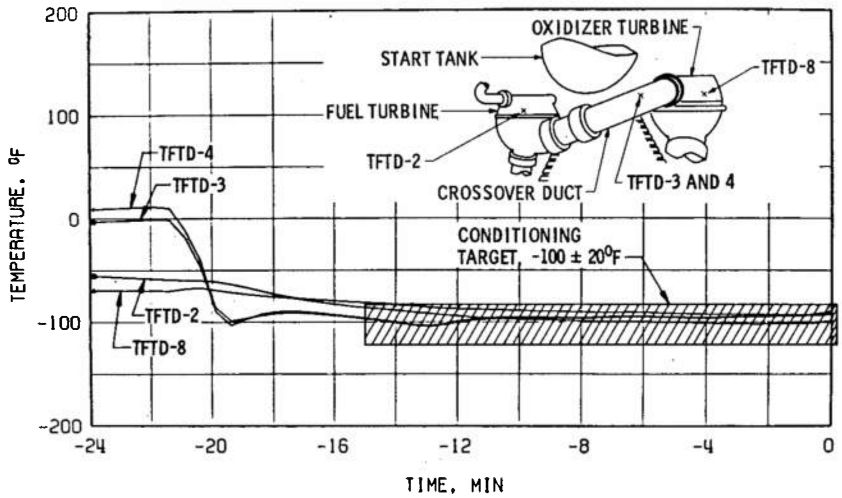
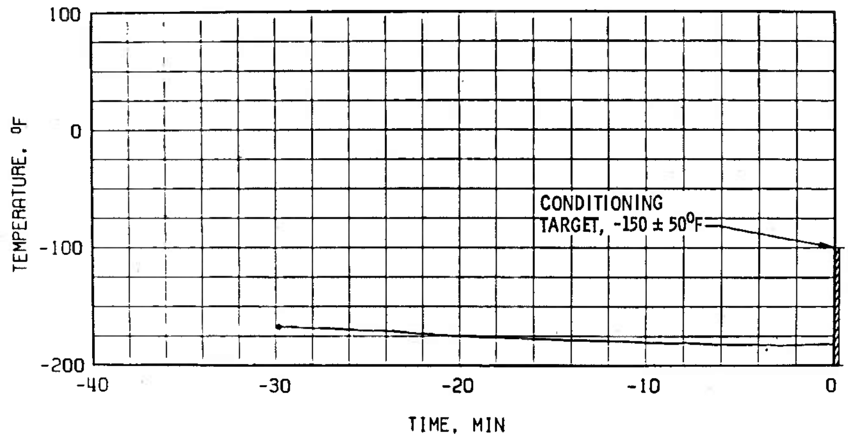


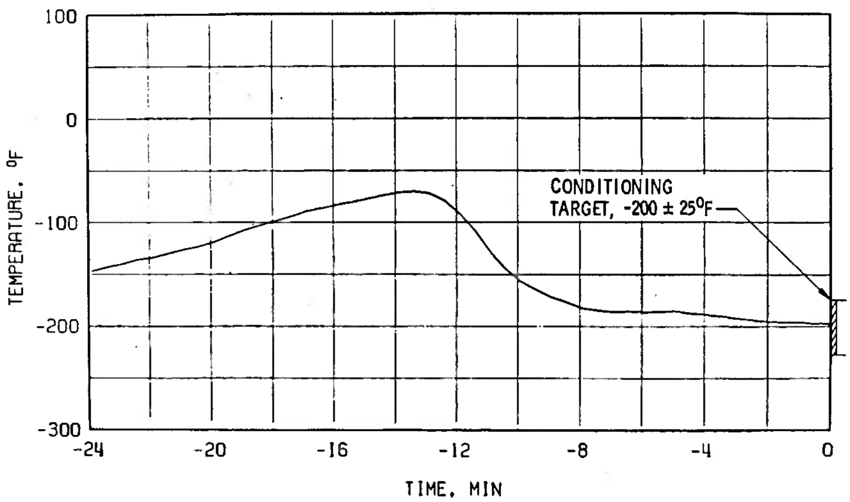
Fig. 63 Fuel Pump Start Transient Performance, Firing 41C



a. Crossover Duct, TFTD

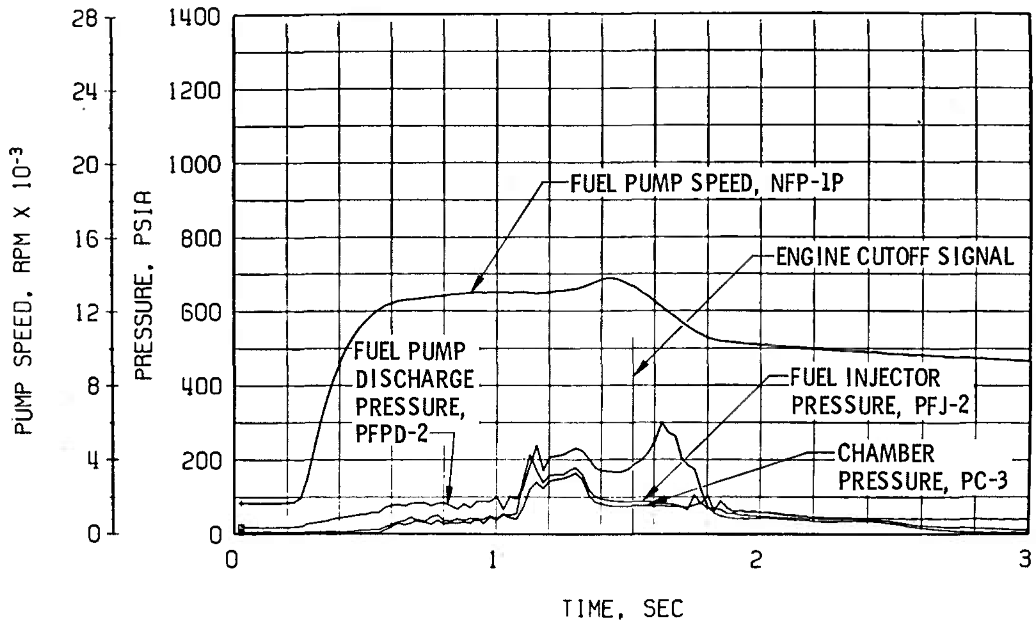


b. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

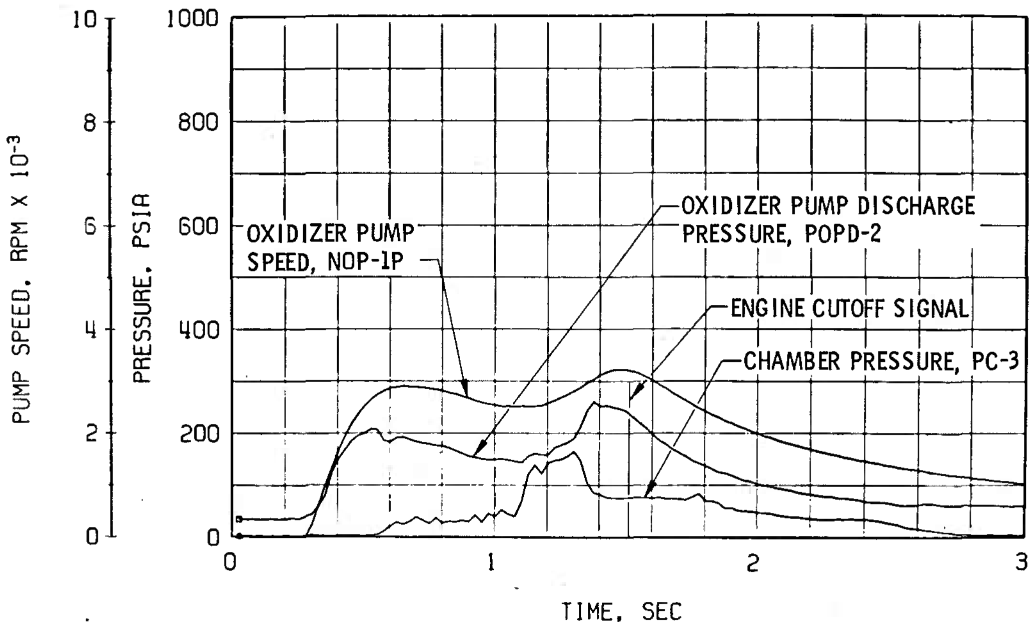


c. Thrust Chamber Throat, TTC-1P

Fig. 64 Thermal Conditioning History of Engine Components, Firing 41D

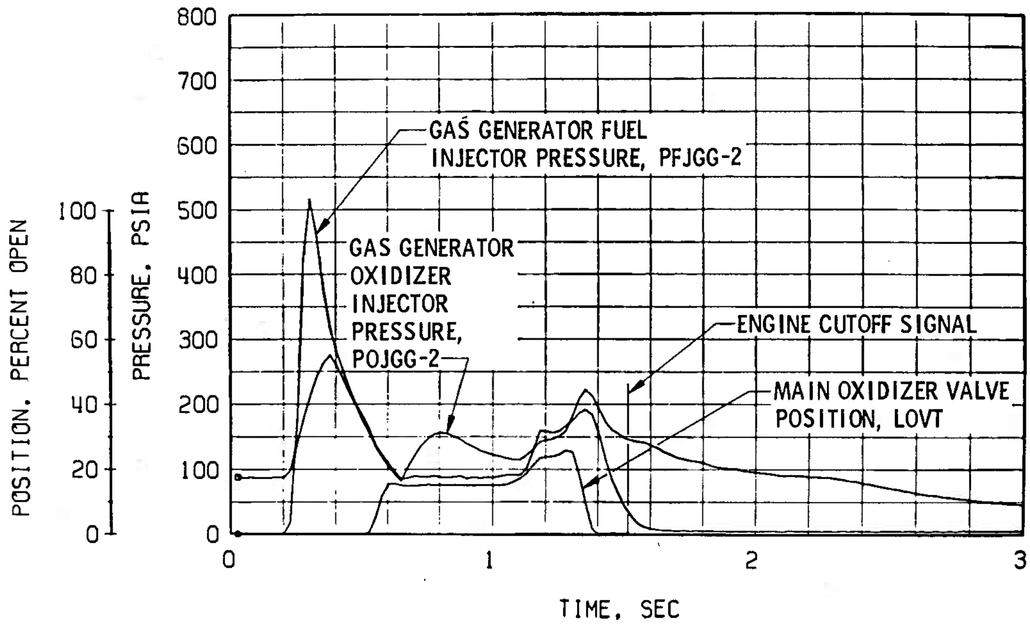


a. Thrust Chamber Fuel System

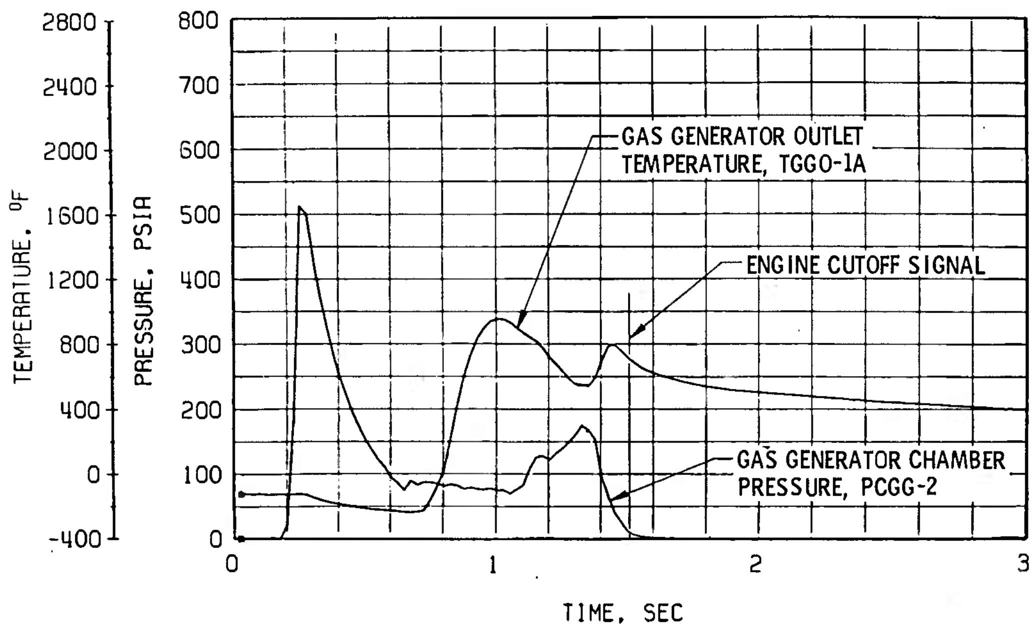


b. Thrust Chamber Oxidizer System

Fig. 65 Engine Transient Operation, Firing 41D

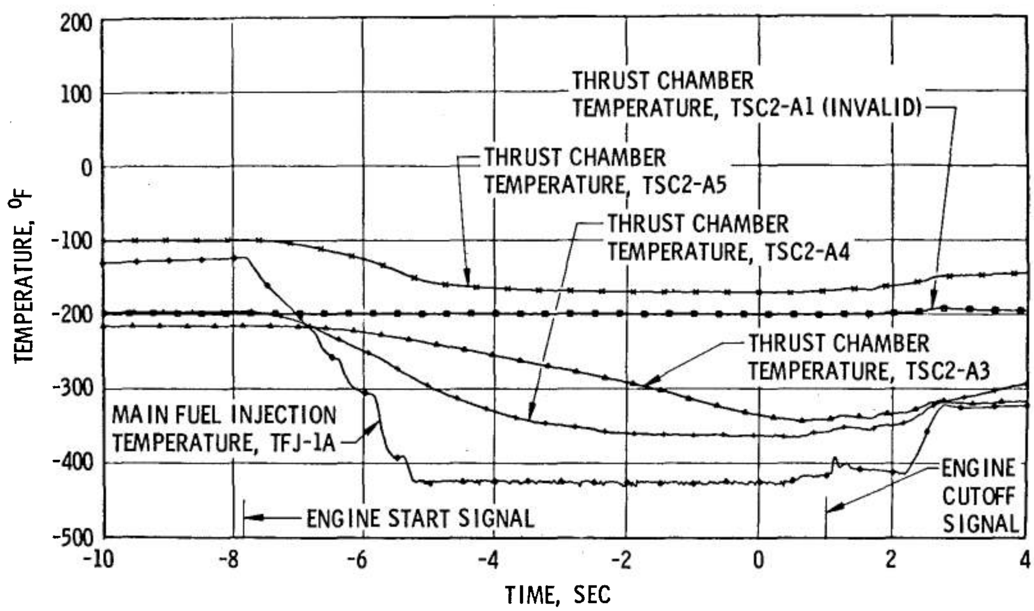


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position

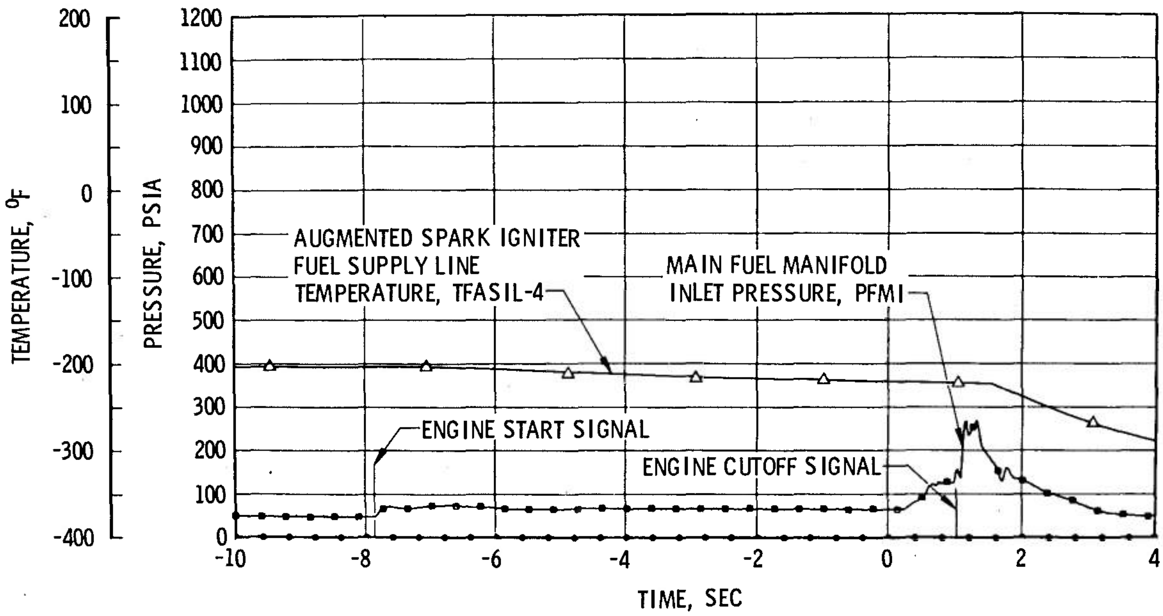


d. Gas Generator Chamber Pressure and Temperature

Fig. 65 Continued

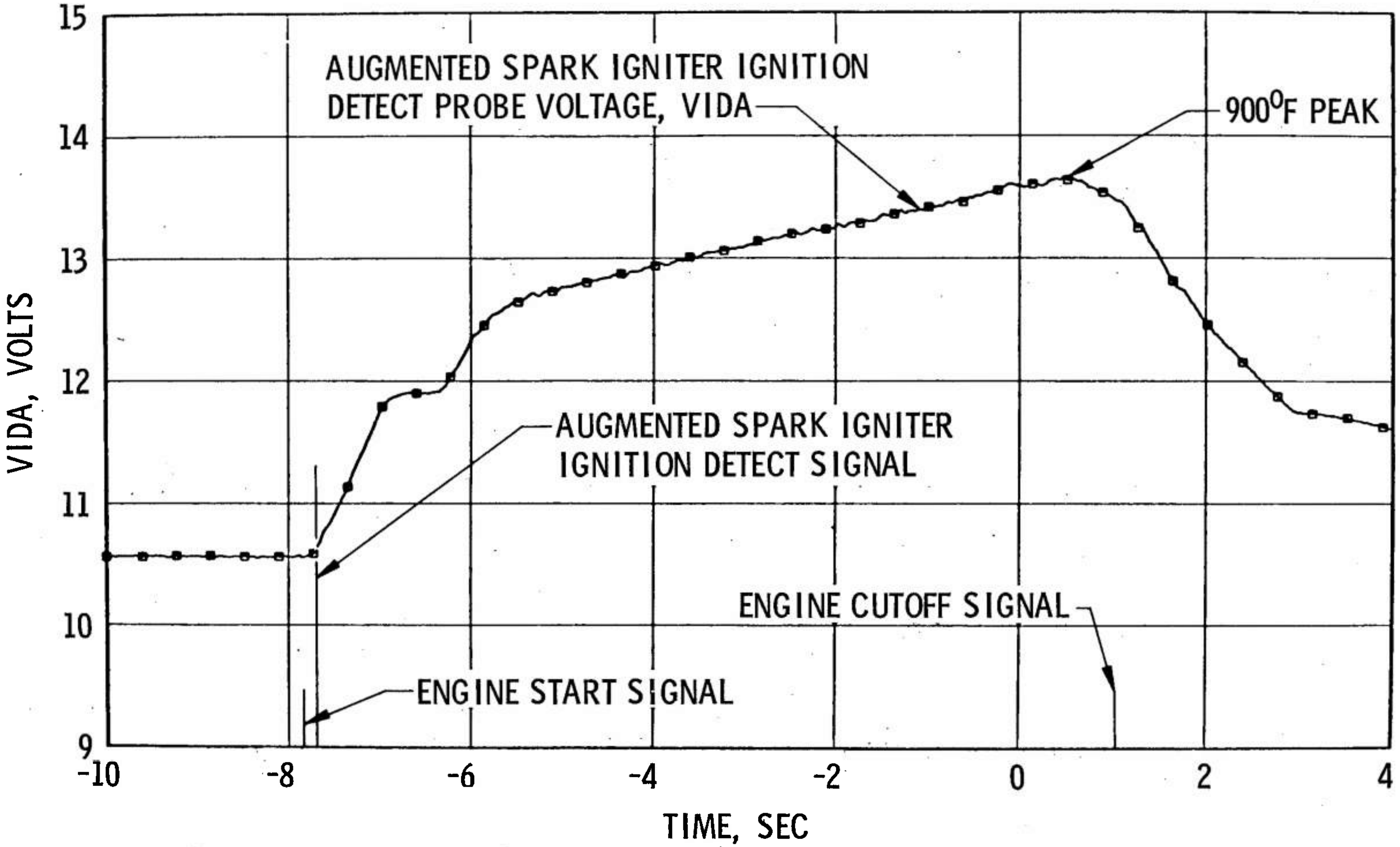


e. Thrust Chamber Temperature Transient



f. Augmented Spark Igniter Fuel Supply Line Pressure and Temperature Transient, Start

Fig. 65 Continued



g. Augmented Spark Igniter Ignition Detect Probe Temperature Transient, Start

Fig. 65 Concluded

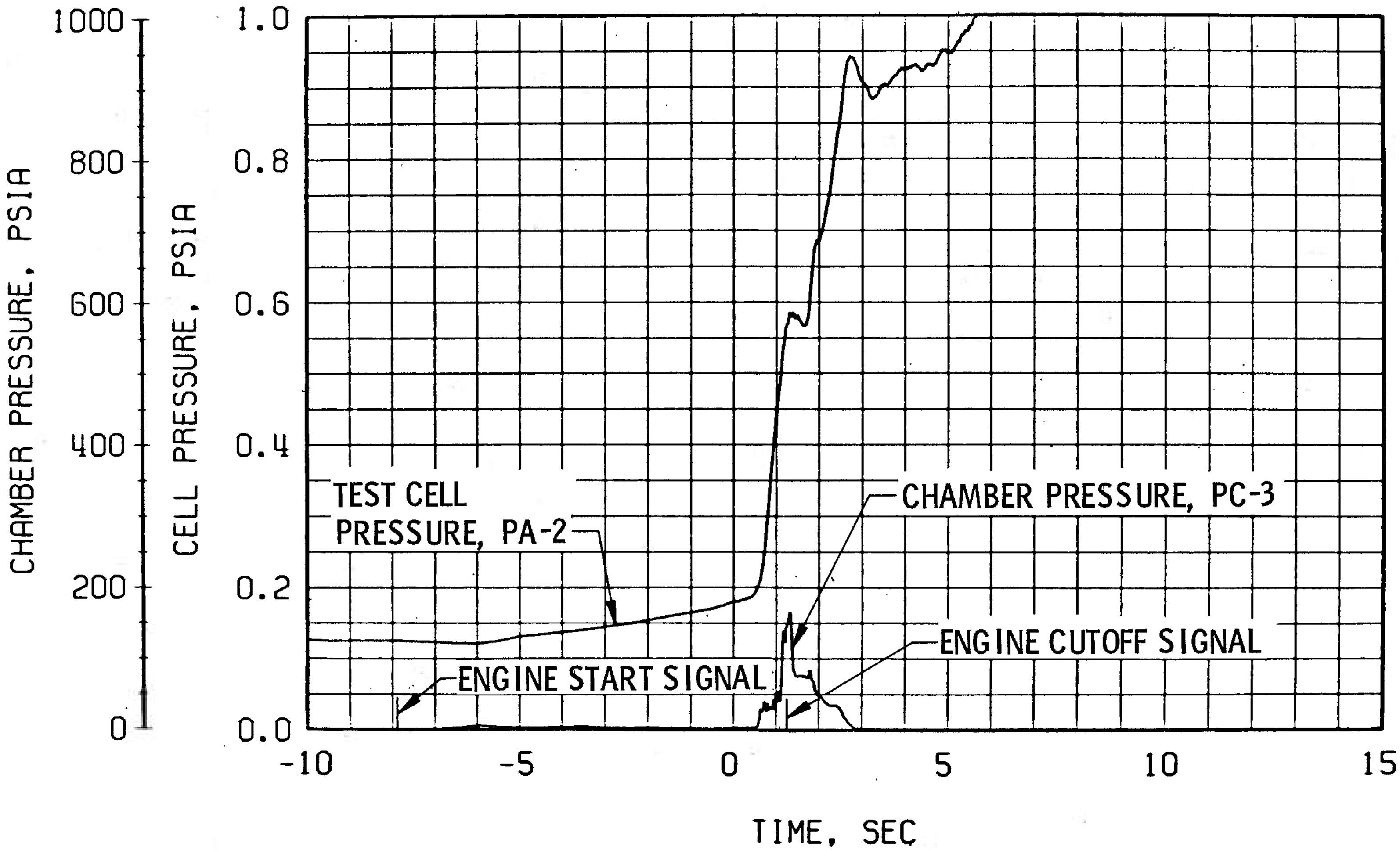


Fig. 66 Engine Ambient and Combustion Chamber Pressures, Firing 41D

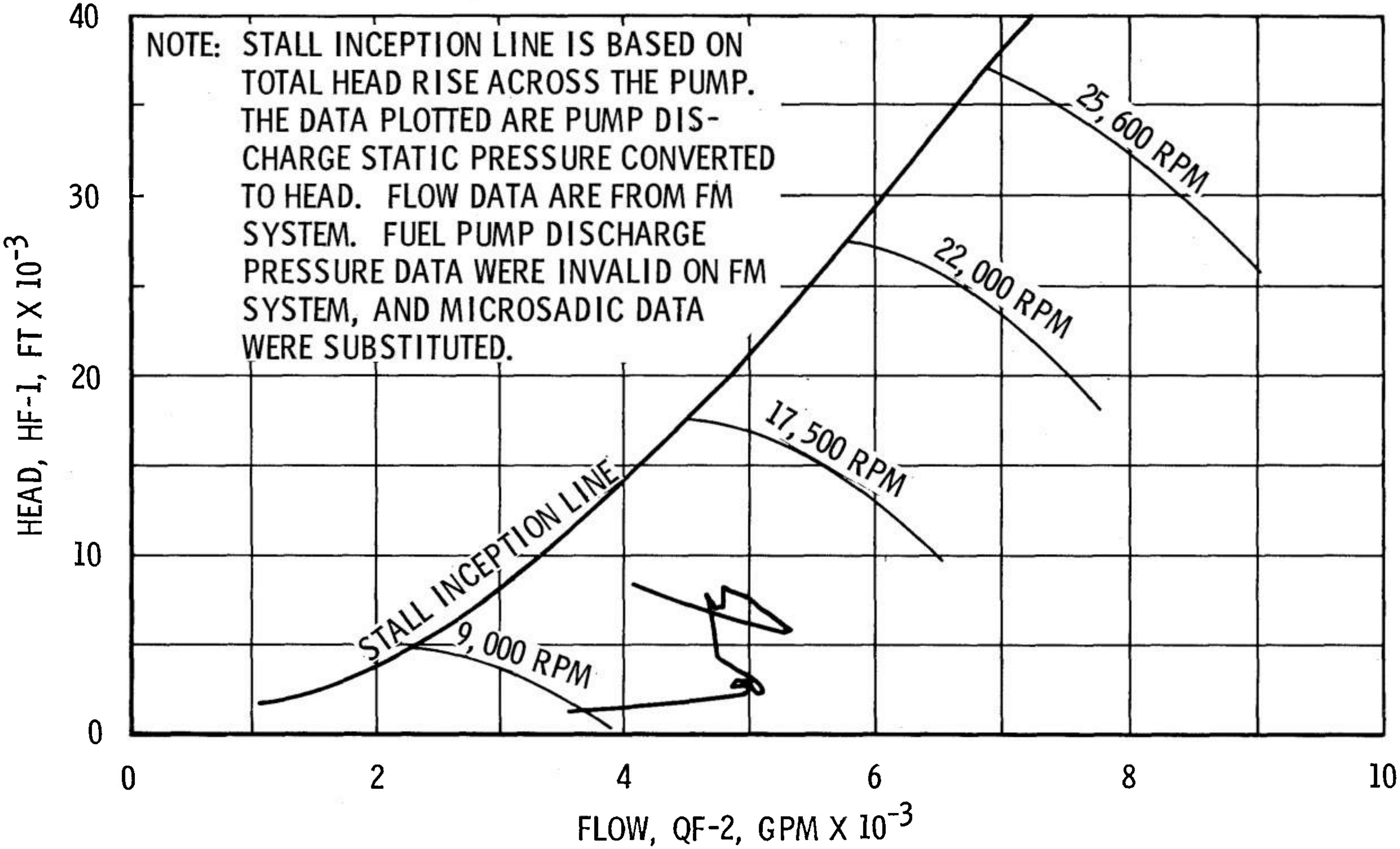
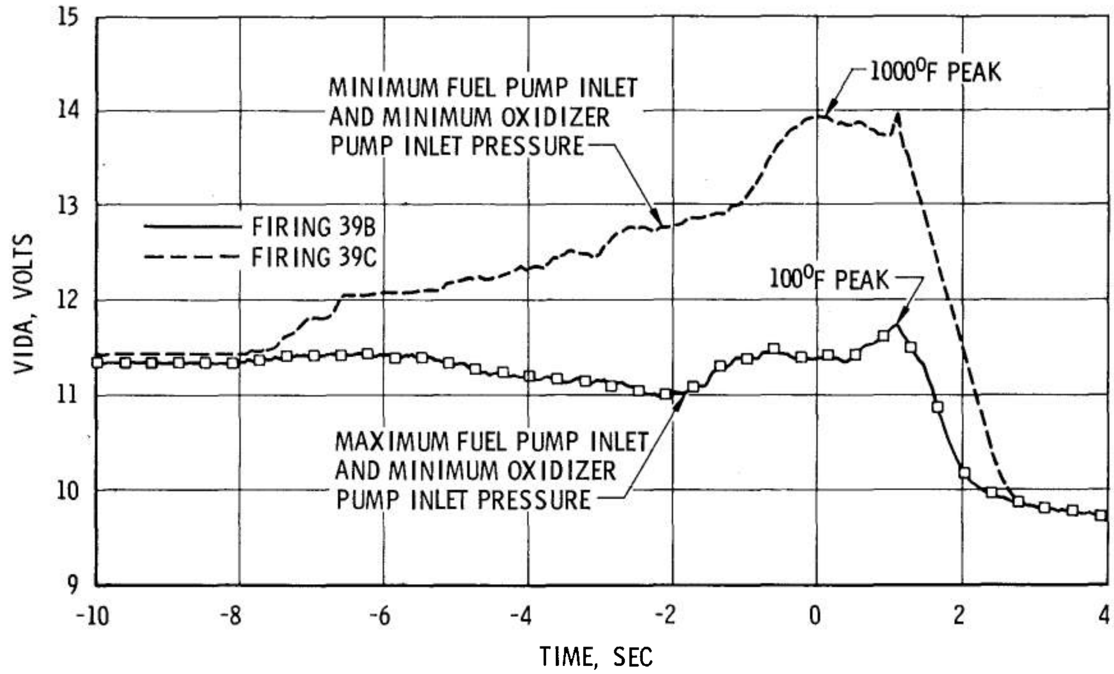
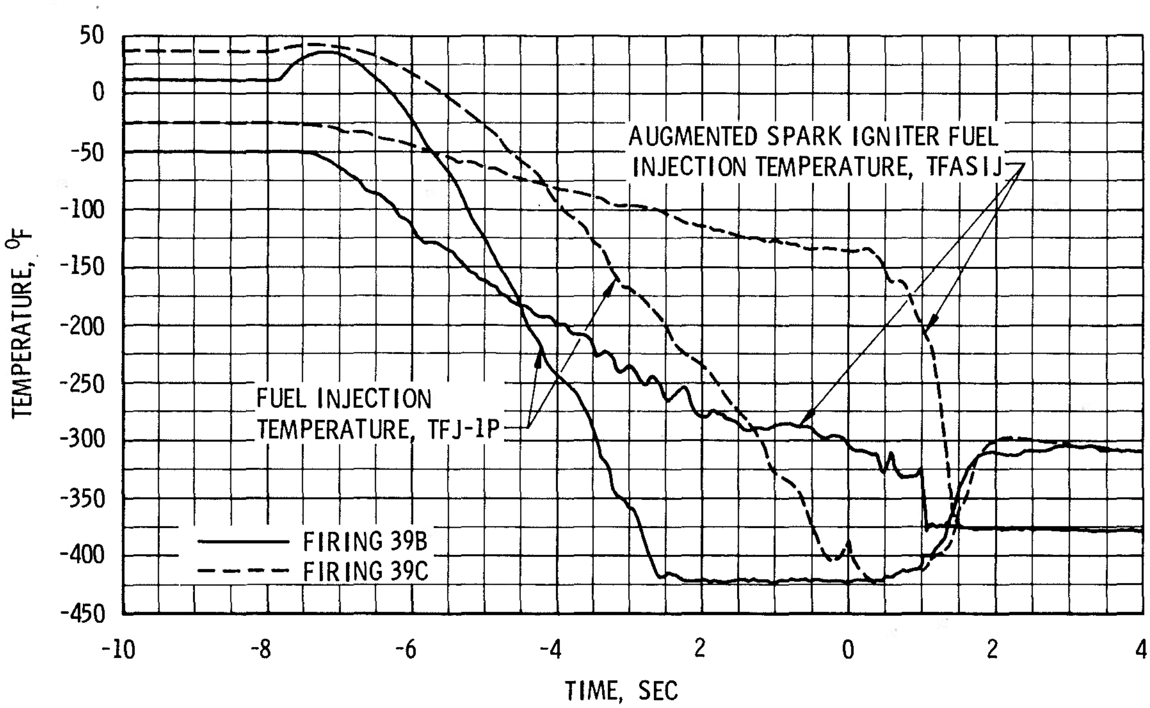


Fig. 67 Fuel Pump Start Transient Performance, Firing 41D

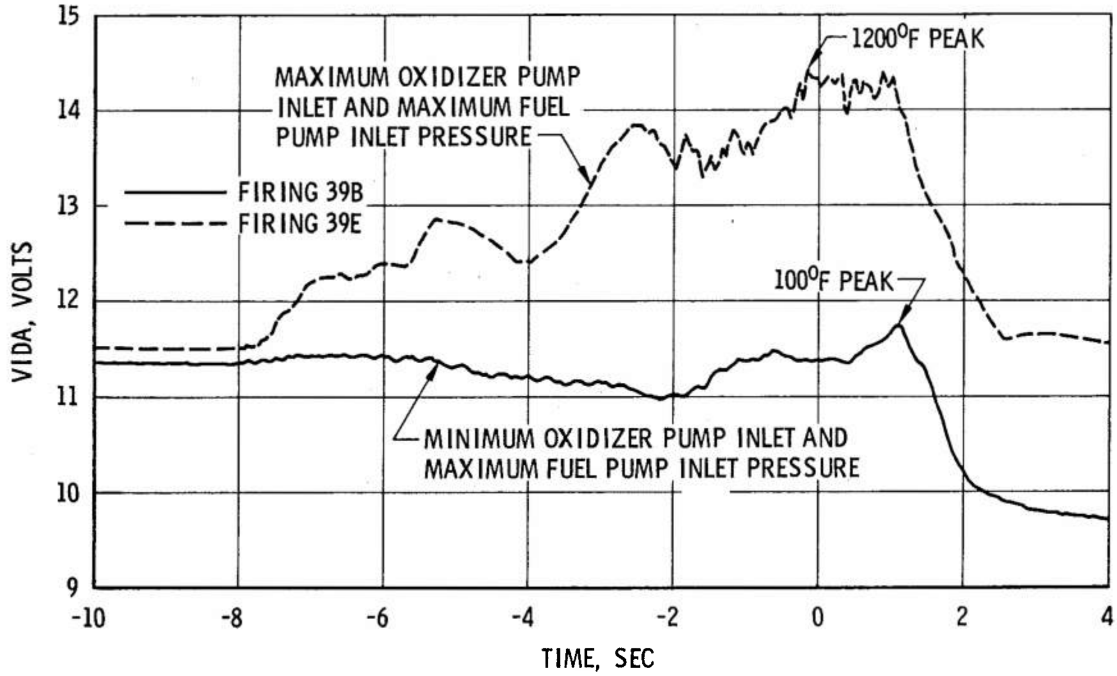


a. Augmented Spark Igniter Ignition Detect Voltage Transients, VIDA

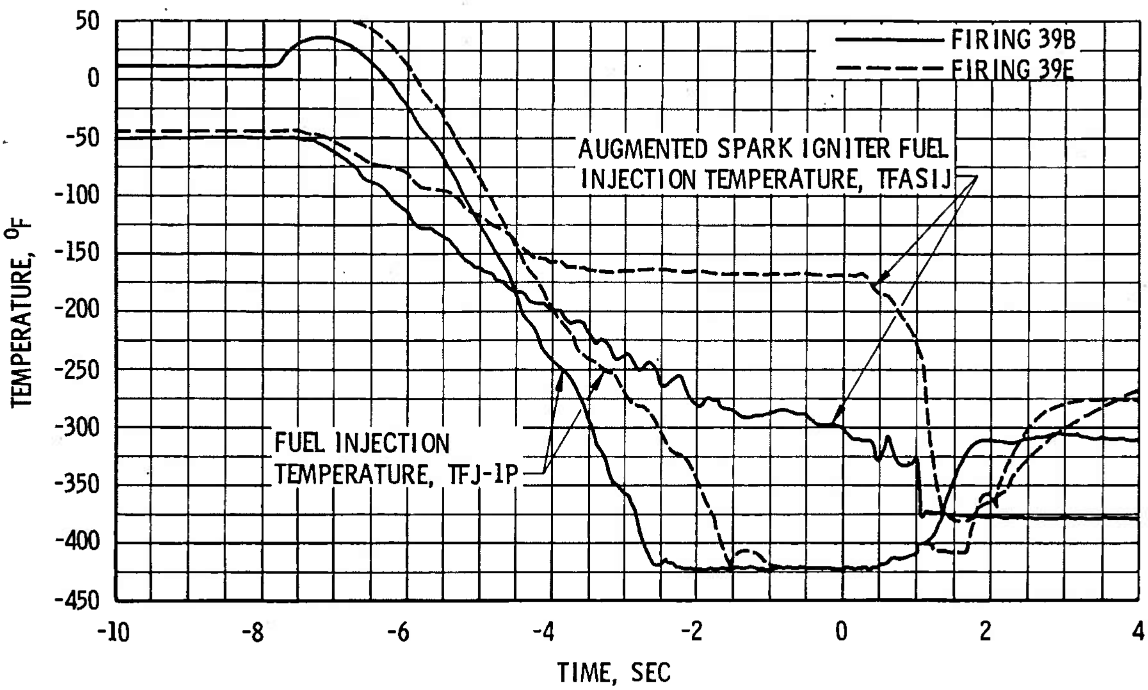


b. Augmented Spark Igniter Fuel Line Childown Rates

Fig. 68 Augmented Spark Igniter Temperature Comparison, Firings 39B and 39C

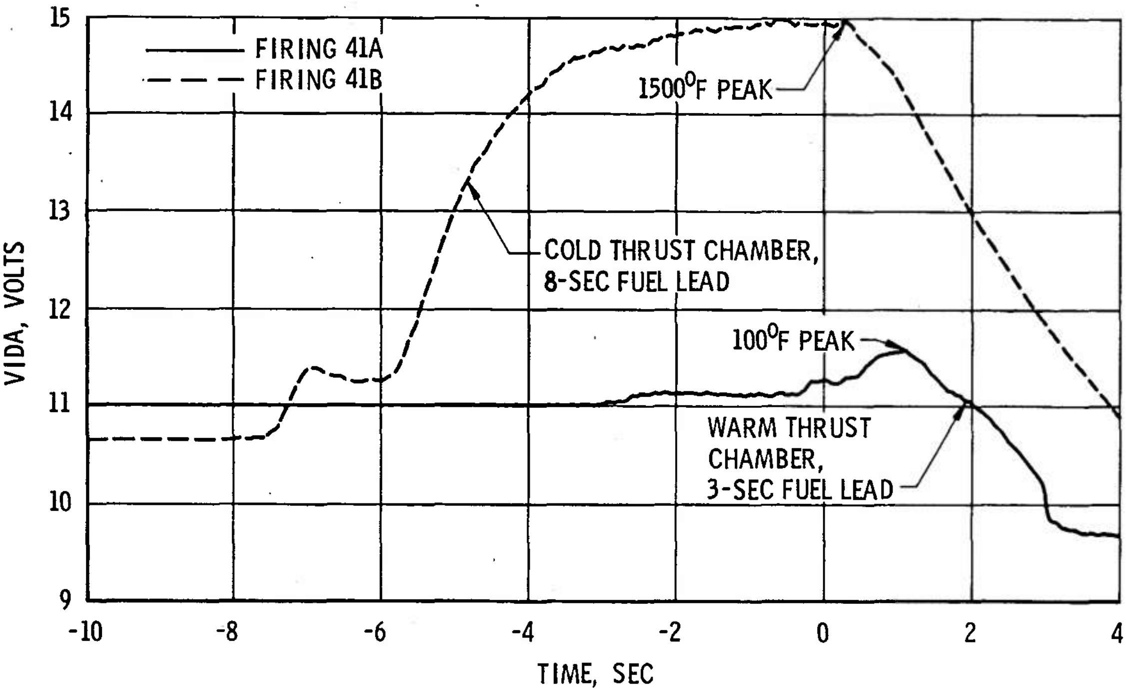


a. Augmented Spark Igniter Ignition Detect Voltage Transients, VIDA

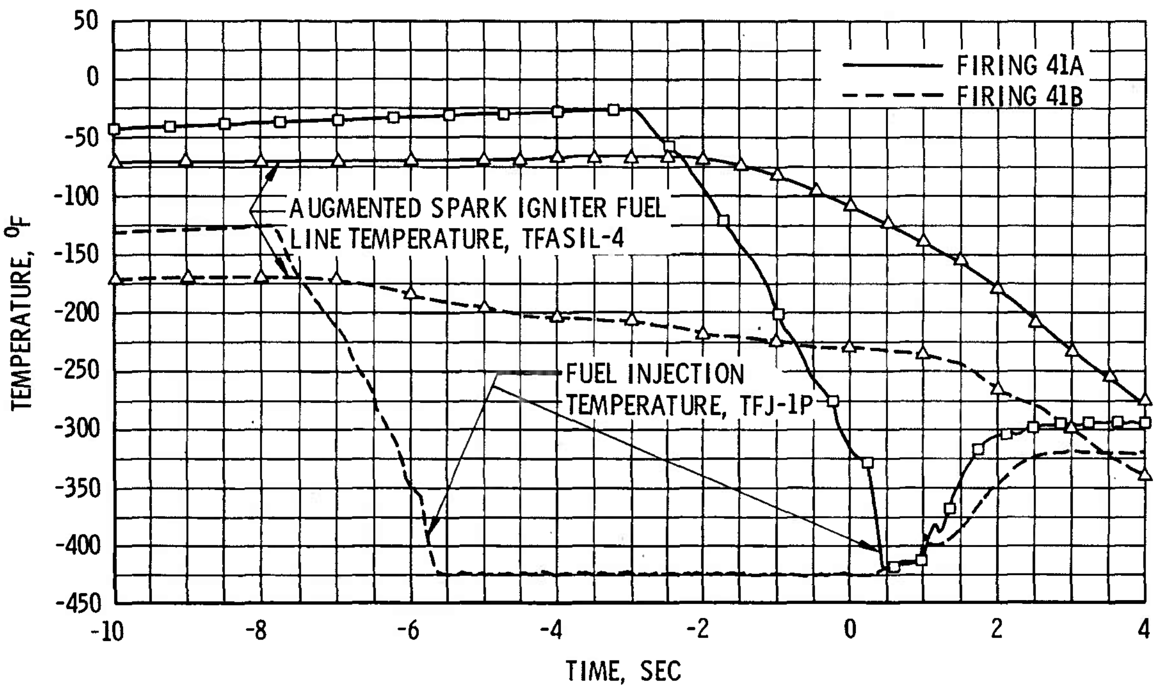


b. Augmented Spark Igniter Fuel Line Childown Rates

Fig. 69 Augmented Spark Igniter Temperature Comparison, Firings 39B and 39E

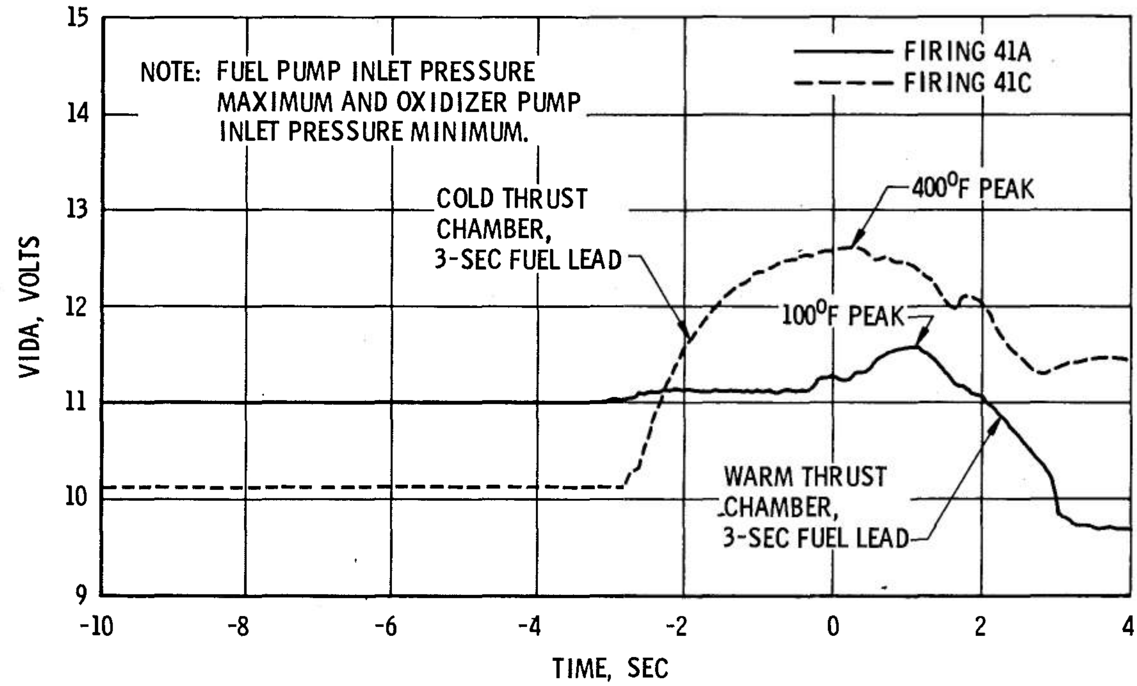


a. Augmented Spark Igniter Ignition Detect Voltage Transients, VIDA, Firings 41A and 41B

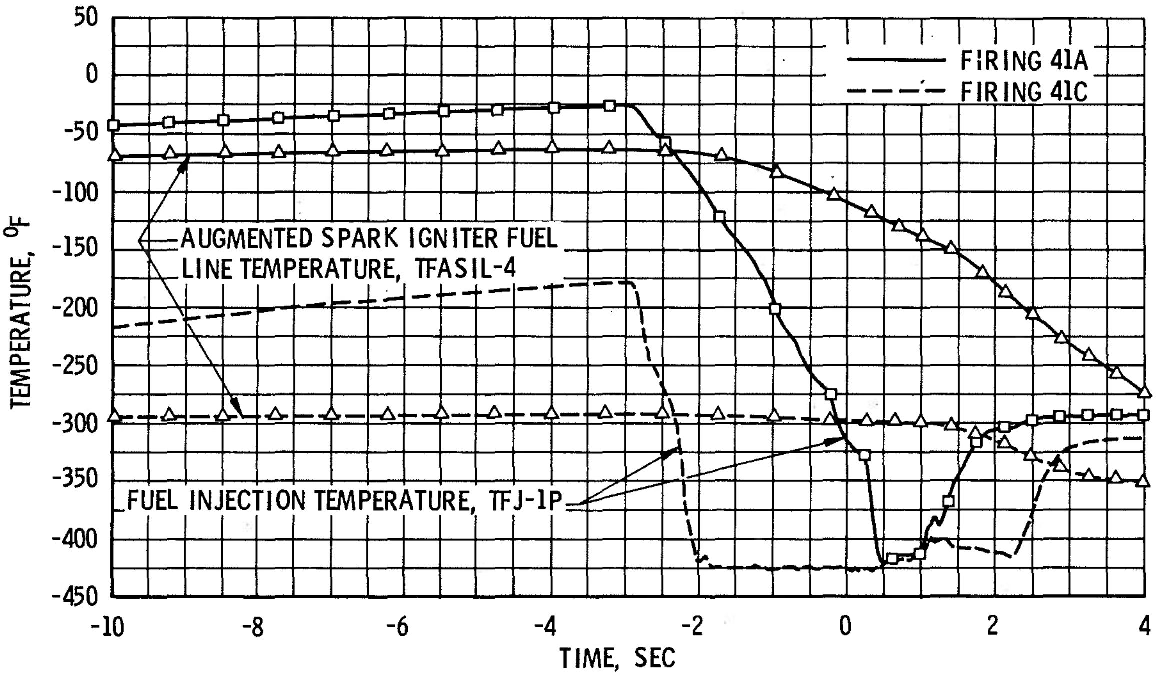


b. Augmented Spark Igniter Fuel Line Chilldown Rates, Firings 41A and 41B

Fig. 70 Augmented Spark Igniter Temperature Comparison, Firings 41A, 41B, and 41C

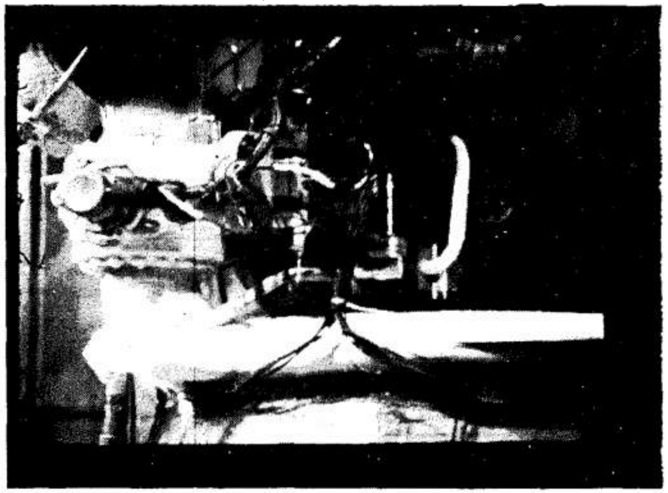


c. **Augmented Spark Igniter Ignition Detect Voltage Transient, VIDA, Firings 41A and 41C**

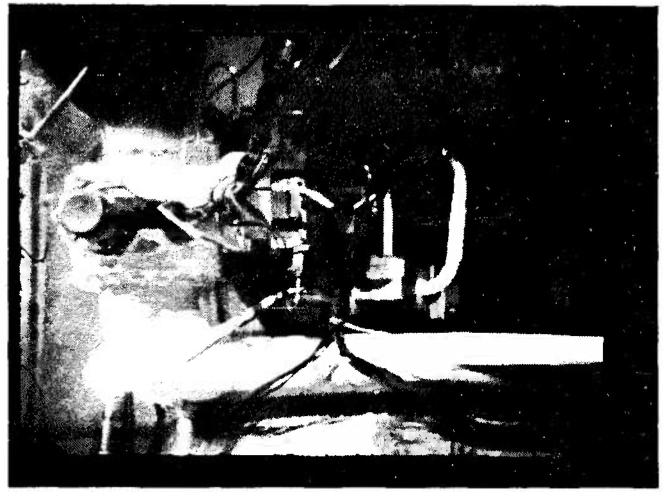


d. **Augmented Spark Igniter Fuel Line Chilldown Rates, Firing 41A and 41C**

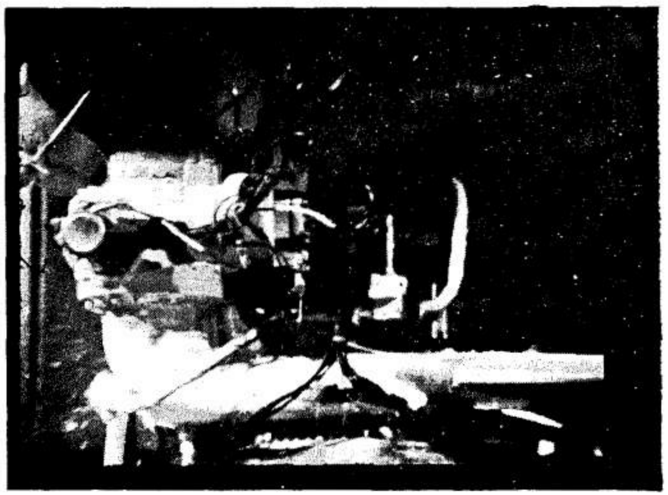
Fig. 70 Concluded



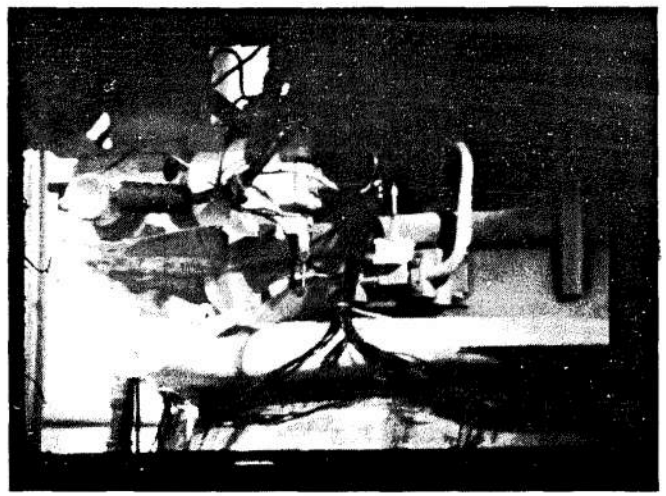
a. Firing 41A at Engine Start



b. Firing 41A at $t_0 + 25$ sec

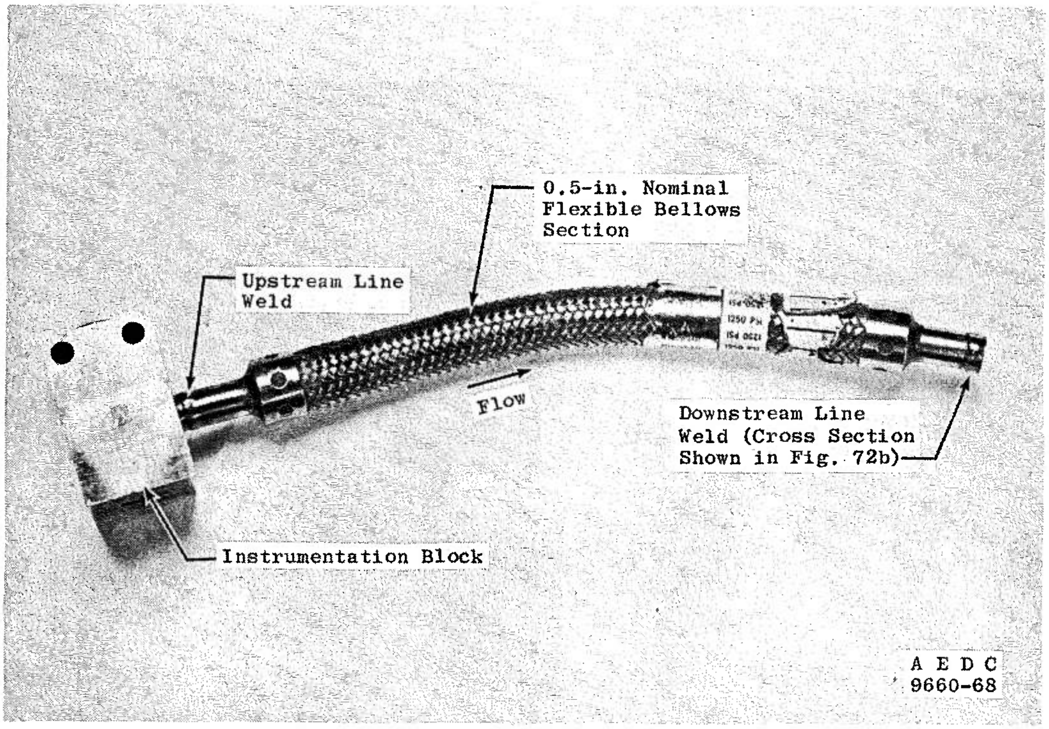


c. During Blowback after Cutoff of Firing 41A

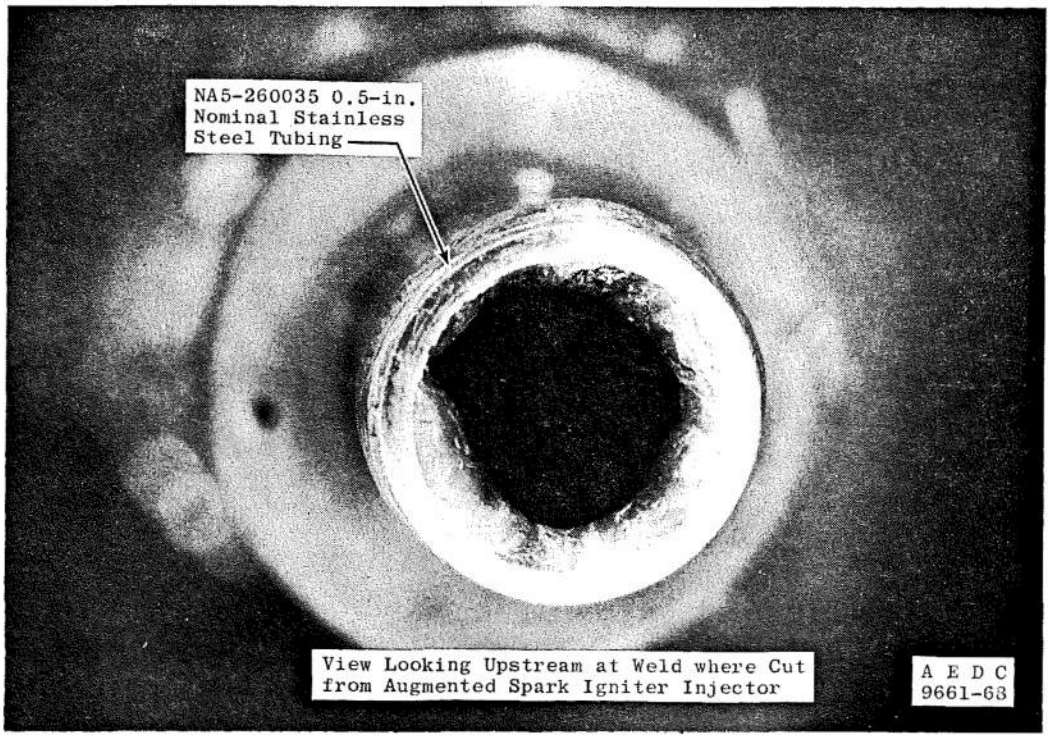


d. Firing 41D at Engine Start

Fig. 71 Frost Accumulation on the Augmented Spark Igniter Fuel Supply Line, Test 41



a. Upper Fuel Line Assembly NA5-260035 Removed from Engine S/N J-2047



b. Upper Fuel Line Assembly Downstream Line Weld Cross Section

Fig. 72 Upper Augmented Spark Igniter Fuel Line Assembly Weld Detail

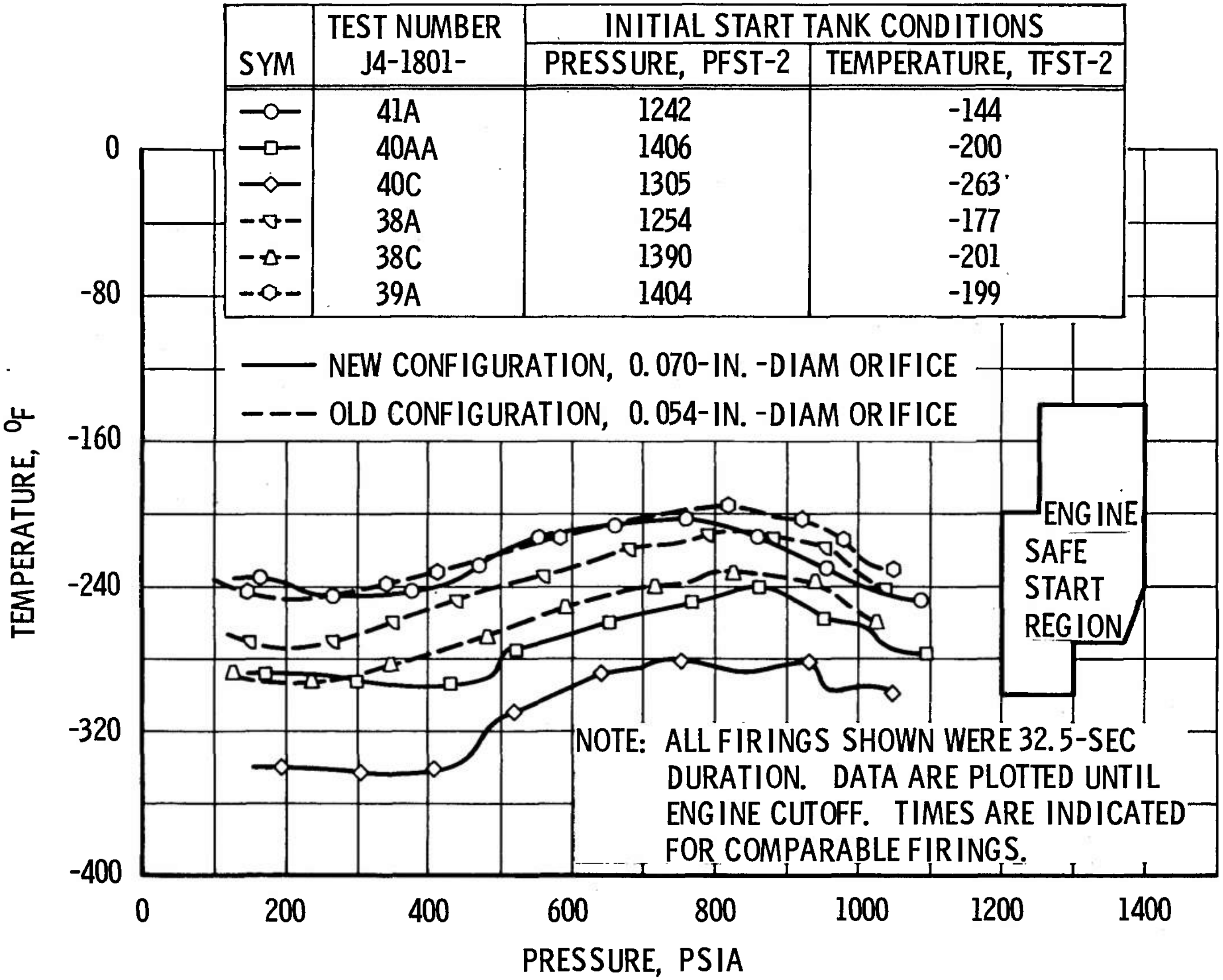


Fig. 73 Start Tank Refill Data Comparison for Enlarged Topping Line Orifice

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	460390-181	4072328
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0038
Augmented Spark Igniter — Test 39	206280-81	4078806
Augmented Spark Igniter — Tests 40 and 41	309360-91	4071414
Gas Generator Fuel Injector and Combustor	308360-11	4088543
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4091740
Helium Regulator Assembly	558130-111	4072892
Electrical Control Package	502670-51	4087776
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062181
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040-31	4062168
Start Tank Discharge Valve	304386	40865957
Oxidizer Turbine Bypass Valve	409940	4062266
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558065	8275908
Ignition Phase Control Valve	558065	8313742
Helium Control Valve	NA5-27273-1	340910
Start Tank Vent and Relief Valve	557848	4092989
Helium Tank Vent Valve	NA5-27273-1	328191
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure-Actuated Shutdown Valve Assembly	558127-11	4087861
Pressure-Actuated Purge Control Valve	558126	4089662
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe — Tests 39	NA5-27298T2	321
Restartable Ignition Detect Probe — 40	NA5-27298T2	338
Restartable Ignition Detect Probe — 41	NA5-27298T2	202

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Date Effective	Comments
Gas Generator Oxidizer Supply Line	RD251-4106	0.274 in.	June 1, 1968	Pretest 41
Augmented Spark Igniter Oxidizer Supply Line	309358	0.125 in.	May 29, 1968	Pretest 40
Augmented Spark Igniter Fuel Supply Line	309355	0.263 in. 0.302 in.	May 29, 1968 June 1, 1968	Pretest 40 Pretest 41
Main Oxidizer Valve Closing Control	410437-084	8.45 scfm	April 17, 1968	Thermostatic Orifice
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430 in. 1.600 in.	May 24, 1968 June 1, 1968	Pretest 40 Pretest 41
Gas Generator Fuel Supply Line	RD251-4107	0.508 in.	March 25, 1968	
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.0 in.	January 18, 1966	Installed on Engine before Shipment to AEDC
Start Tank Topping Line	RD273-1026 501 459	0.054 in. 0.070 in.	January 18, 1966 May 1, 1968	Installed on Engine Pretest 40

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-38 AND J4-1801-41)

Modification Number	Completion Date	Description
RFD[1]-AEDC 21-68	April 28, 1968	Modified Augmented Spark Igniter Fuel Line Installed
	Test J4-1801-39 April 30, 1968	
RFD-AEDC 22-68	May 9, 1968	Turbine Hardware Thermocouple Installation
RFD-AEDC 23-68	May 9, 1968	Thrust Chamber Skin Thermocouples Installed; TSC2-1, -12, -13, -17, -20, and -24
RFD-AEDC 24-68	May 9, 1968	Modified Augmented Spark Igniter Assembly Installed; P/N 309360-91, S/N 4071414
RFD-AEDC 25-68	May 8, 1968	Monitoring of Fuel Pump Primary Seal Drain Pressure and Turbine Seal Drain Temperature
RFD-AEDC 26-68	May 8, 1968	Gas Generator Oxidizer Bootstrap Line Thermocouples Installed
RFD-AEDC 27-68	May 10, 1968	Provision for Start Tank Emergency Vent System
RFD-AEDC 28-68	May 10, 1968	Helium Regulator Modification
RFD-AEDC 29-68	May 22, 1968	Reorificing of Engine J-2047; Oxidizer Turbine Bypass Valve Nozzle 1.430-in. Diameter
RFD-AEDC 30-68	May 27, 1968	CF2A Instrumentation Line
RFD-AEDC 35-4-67	May 29, 1968	Augmented Spark Igniter Probe Shim Installed, 0.044 in.
	Test J4-1801-40 May 30, 1968	
RFD-AEDC 31-68	May 31, 1968	Reorificing of Engine J-2047; Augmented Spark Igniter Fuel Orifice, 0.302-in. Diameter Gas Generator Oxidizer Valve, 0.274-in. Diameter Oxidizer Turbine Bypass Valve, 1.600-in. Diameter
RFD-AEDC 35-5-67	June 1, 1968	Augmented Spark Igniter Probe Shim Installed, 0.024 in.
	Test J4-1801-41 June 5, 1968	

[1]RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-38 AND J4-1801-41)

Replacement	Completion Date	Component Replaced
UCR[1] 005119	April 28, 1968	Augmented Spark Igniter Ignition Detect Probe; P/N NA5-27298T2, S/N 321
Test J4-1801-39 April 30, 1968		
UCR 005119	May 29, 1968	Augmented Spark Igniter Ignition Detect Probe; P/N NA5-27298T2, S/N 338
Test J4-1801-40 May 30, 1968		
UCR 005127	June 1, 1968	Augmented Spark Igniter Ignition Detect Probe; P/N NA5-27298T2, S/N 202
Test J4-1801-41 June 5, 1968		

[1]UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

		Time, min (t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10)
Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect	10 min (t - 70 to t - 60); ← Propellant Drop; 2-min Minimum Following Recirculation →; 1 to 3 min →; ←
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm	15 min (to t - 60); 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port COA3)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min (t - 60 onward); On at Engine Cutoff →; 10 min (t - 0 to t + 10)
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm	15 min (to t - 60); Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to → 15 min (from t - 60)
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	(to t - 0); On at Engine Cutoff; 10 min (t - 0 to t + 10)
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min	15 min (to t - 0)
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F	(t - 60 to t - 0)
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	30 min (t - 30 to t - 0)
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	1 (t - 70 to t - 0)
Main Oxidizer Valve Actuator Temperature Conditioning	Helium; -300°F to Ambient	1 (t - 70 to t - 0)

[1]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS
a. Test J4-1801-39

Firing Number: J4-1801-		39A Target	39A Actual	39B Target	39B Actual	39C Target	39C Actual	39D Target	39D Actual	39E Target	39E Actual
Time of Day, hr/Firing Date		1119	4/30/68	1143	4/30/68	1247	4/30/68	1336	4/30/68	1457	4/30/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	99,500	100,000	99,500	100,000	100,500	100,000	102,500	100,000	109,000
Firing Duration, sec(1)		32.5	32.571	7.5	7.589	7.5	7.589	7.5	7.588	1.15	1.150
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	41^{+1}_{-0}	41.8	41^{+1}_{-0}	41.8	27^{+1}_{-0}	27.2	41^{+1}_{-0}	42.2	41^{+1}_{-0}	40.6
	Temperature, °F	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-420.9	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.6	-421.4 ± 0.4	-421.4
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33^{+1}_{-0}	33.9	33^{+1}_{-0}	34.0	33^{+1}_{-0}	33.3	33^{+1}_{-0}	33.8	45^{+1}_{-0}	46.0
	Temperature, °F	-295.0 ± 0.4	-295.4	-295.0 ± 0.4	-295.1	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-295.0	-295.0 ± 0.4	-294.7
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1243	1300 ± 10	1301	1250 ± 10	1249	1250 ± 10	1246	1300 ± 10	1297
	Temperature, °F	-140 ± 10	-143	-260 ± 10	-263	-140 ± 10	-144	-140 ± 10	-145	-200 ± 10	-203
Helium Tank Conditions at Engine Start	Pressure, psia	---	2107	---	2035	---	2315	---	2221	---	2126
	Temperature, °F	---	-142	---	-260	---	-144	---	-146	---	-201
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-80^{+20}_{-10}	-86 / -91	50 ± 50	50 / 36	50 ± 50	16 / 21	-275 ± 25	-279 / -285	50 ± 50	59 / 60
	Average(4)		-132		+42		+45		-294		+65
Crossover Duct Temperature at Engine Start, °F(3)	TFTD-2	0 ± 15	-10	---	435	-100 ± 15	-98	-100 ± 15	-105	---	60
	TFTD-3		5	170^{+15}_{-0}	169		-89		-99	---	75
	TFTD-8		-5	---	408		-92		-106	---	63
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F(2)		-150 ± 50	-160	-150 ± 50	-154	-150 ± 50	-165	-150 ± 50	-170	---	-174
Fuel Lead Time, sec(1)		3.0	3.013	8.0	7.919	8.0	7.919	3.0	3.014	8.0	7.917
Propellant in Engine Time, min		30 (min)	119	---	23	30 (min)	63	30 (min)	48	30	80
Propellant Recirculation Time, min		10 (min)	10	10	10	10	10	10	10	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2A	> -100	32	> -100	30	> -100	16	> -100	36	---	35
	TOBS-3	---	---	---	---	---	---	---	---	---	---
	TOBS-4	---	-0.4	---	2	---	-16	---	3	---	1
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		---	-7	---	-8	---	-32	---	-32	---	-33
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t_0	VSC-1/Time / VSC-2/Time	---	38/1.012 / 15/1.014	---	35/0.949 / 28/0.950	---	12/1.078 / 11/1.080	---	11; 21/.985; 1.252 / [illegible]	---	10/0.970 / 9/0.973
Gas Generator Outlet Temperature, °F	Initial Peak	---	1326	---	1369	---	719	---	1371	---	1648
	Second Peak	---	None	---	1395	---	---	---	---	---	1977
Augmented Spark Igniter Ignition Detected Time, sec, from Engine Start		---	3.442	---	0.793	---	0.356	---	0.205	---	0.242
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)(1)		---	1.015	---	0.963	---	1.073	---	1.048	---	0.974
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)(1)		---	1.014	---	1.105	---	1.082	---	0.990	---	1.109
Main-Stage Pressure No. 2, sec (Ref. t_0)(1)		---	1.702	---	1.663	---	1.962	---	1.772	---	---
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)(1)		---	1.972	---	2.050	---	2.607	---	2.067	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / ---	Open / ---	Open / ---	Open / ---	Null / ---	Null / ---	Null / ---	Null / ---

Notes: (1) Data reduced from oscillogram.
(2) Component conditioning to be maintained within limits for last 15 min before engine start.
(3) Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
(4) Thrust chamber temperature gradient (throat-to-exit) not to exceed 25°F.

TABLE VI (Continued)
b. Test J4-1801-40

Firing Number: J4-1801-		40A Target	40A Actual	40AA Target	40AA Actual	40B Target	40B Actual	40C Target	40C Actual	40D Target	40D Actual
Time of Day, hr/Firing Date		0936	5/30/68	1041	5/30/68	1116	5/30/68	1402	5/30/68	1431	5/30/68
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	88,000	100,000	92,000	100,000	103,000	100,000	99,000	100,000	104,000
Firing Duration, sec①		32.5	2.182	32.5	32.577	7.5	7.590	32.5	32.577	7.5	7.590
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	27^{+0}_{-1}	26.7	41^{+1}_{-0}	41.6	27^{+0}_{-1}	26.5	27^{+0}_{-1}	27.5	41^{+1}_{-0}	41.2
	Temperature, °F	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-420.6
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45^{+1}_{-0}	46.1	45^{+1}_{-0}	46.0	45^{+1}_{-0}	45.6	45^{+1}_{-0}	45.3	45^{+1}_{-0}	45.6
	Temperature, °F	-295.0 ± 0.4	-295.1	-295.0 ± 0.4	-295.1	-295.0 ± 0.4	-295.2	-295.0 ± 0.4	-294.4	-295.0 ± 0.4	-294.1
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1404	1400 ± 10	1406	1300 ± 10	1302	1300 ± 10	1305	1300 ± 10	1301
	Temperature, °F	-200 ± 10	-199	-200 ± 10	-200	-265 ± 10	-267	-265 ± 10	-263	-265 ± 10	-284
Helium Tank Conditions at Engine Start	Pressure, psia	---	2191	---	2189	---	2133	---	2220	---	2159
	Temperature, °F	---	-195	---	-196	---	-261	---	-250	---	-282
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat, TSC-2	-80^{+20}_{-10}	-89 / -100	-80^{+20}_{-10}	-86 / -96	50 ± 50	63 / 51	-200 ± 25	-194 / -211	60 ± 50	78 / 60
	Average		-102		-102		+37		-236		+46
Crossover Duct Temperature at Engine Start, °F①	TFTD-2	0 ± 25	-9	0 ± 25	6	170^{+15}_{-0}	396	50 ± 25	17	170^{+15}_{-0}	406
	TFTD-3		-13		24		172		67		177
	TFTD-8		-4		2		364		49		378
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F③		-150 ± 50	-152	-150 ± 50	-171	-150 ± 50	-173	-150 ± 50	-134	-150 ± 50	-156
Fuel Lead Time, sec①		3.0	3.015	3.0	3.002	8.0	7.919	8.0	7.919	8.0	7.920
Propellant in Engine Time, min		30 (min)	116	---	64	30 (min)	34	30	165	30	26
Propellant Recirculation Time, min		10 (min)	10	10	10	10	10	10	10	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2	---	21	---	10	---	-9	---	-27	---	-10
	TOBS-2B	---	9	---	7	---	-10	---	-24	---	+19
	TOBS-4	---	---	---	---	---	---	---	---	---	---
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		---	N/A	---	-46	---	-49	---	-55	---	-54
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t_0	VSC-1 / Time	--- / ---	5 / 0.960	---	31 / 0.955	---	3 / 1.234/1.028	---	25; 16 / 1.027; 1.234	---	17 / 0.960
Gas Generator Outlet Temperature, °F	Initial Peak	---	N/A	---	1567	---	1716	---	1378	---	1807
	Second Peak	---	N/A	---	1577	---	1824	---	None	---	1767
Augmented Spark Igniter Ignition Detect Time, sec, from Engine Start		---	0.212	---	0.202	---	0.215	---	0.169	---	0.272
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)①		---	0.961	---	0.962	---	0.957	---	1.032	---	0.953
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)①		---	1.153		1.129		1.134		1.027		1.109
Main-Stage Pressure No. 2, sec (Ref. t_0)①		---	1.485	---	1.550	---	1.626	---	1.792	---	1.573
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)①		---	1.741	---	1.829	---	2.000	---	2.164	---	1.945
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Closed / ---	Null / Closed	Null / Closed	Open / ---	Open / ---	Open / ---	Open / Closed	Open / ---	Open / ---

Notes: ① Data reduced from oscillogram.

② Component conditioning to be maintained within limits for last 15 min before engine start.

③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

TABLE VI (Concluded)

c. Test J4-1801-41

Firing Number: J4-1801-		41A Target	41A Actual	41B Target	41B Actual	41C Target	41C Actual	41D Target	41D Actual
Time of Day, hr/Firing Date		1000	6/5/88	1026	6/5/68	1145	6/5/68	1221	6/5/88
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	102,000	100,000	102,500	100,000	105,500	100,000	105,500
Firing Duration, sec[1]		32.5	32.575	7.5	7.590	1.25	1.284	1.25	1.258
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	41^{+1}_{-0}	41.3	41^{+1}_{-0}	41.3	41^{+1}_{-0}	41.5	27^{+0}_{-1}	26.8
	Temperature, °F	-421.4 ± 0.4	-421.3	-421.4 ± 0.4	-421.2	-421.4 ± 0.4	-421.4	-421.4 ± 0.4	-421.7
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33^{+1}_{-0}	33.5	33^{+1}_{-0}	33.7	33^{+1}_{-0}	33.8	33^{+1}_{-0}	33.4
	Temperature, °F	-294.5 ± 0.4	-294.7	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.4
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1242	1300 ± 10	1295	1250 ± 10	1237	1250 ± 10	1243
	Temperature, °F	-140 ± 10	-144	-265 ± 10	-268	-140 ± 10	-140	-140 ± 10	-147
Helium Tank Conditions at Engine Start	Pressure, psia	---	2140	---	2111	---	2486	---	2185
	Temperature, °F	---	-138	---	-262	---	-145	---	-142
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-80^{+20}_{-10}	-83	-200 ± 25	-206	-275 ± 25	-282	-200 ± 25	-198
	Average	---	-109	---	-217	---	-293	---	-220
Crossover Duct Temperature at Engine Start, °F[2]	TFTD-2	0 ± 25	-85	170^{+15}_{-0}	---	-100 ± 20	-106	-100 ± 20	-100
	TFTD-3		2		178		-83		-90
	TFTD-8		-2		146		-95		-93
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F[3]		-150 ± 50	-105	-150 ± 50	-142	-150 ± 50	-180	-150 ± 50	-183
Fuel Lead Time, sec[1]		3.0	3.002	8.0	7.919	3.0	3.020	8.0	7.919
Propellant in Engine Time, min		30 (min)	126	---	25	30	78	30	35
Propellant Recirculation Time, min		10 (min)	10	10	10	10	10	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2	> -100	22	> -100	-8	> -100	-9	> -100	-8
	TOBS-2B	---	11	---	-9	---	-2	---	-8
	TOBS-4	---	---	---	---	---	---	---	---
Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F		---	-180	---	-139	---	-76	---	-72
Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t_0	VSC-1 / Time	--- / ---	134 / 1.008	--- / ---	67 / 0.957	--- / ---	51 / 1.040	--- / ---	58 / 1.086
Gas Generator Outlet Temperature, °F	Initial Peak	---	1128	---	1558	---	1344	---	952
	Second Peak	---	1228	---	1280	---	---	---	---
Augmented Spark Igniter Ignition Detect Time, sec, from Engine Start		---	0.558	---	0.458	---	0.196	---	0.198
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)[1]		---	1.007	---	0.961	---	1.048	---	1.090
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)[1]		---	1.014	---	0.999	---	1.006	---	1.038
Main-Stage Pressure No. 2, sec (Ref. t_0)[1]		---	1.695	---	1.734	---	---	---	---
Time Chamber Pressure Attains 550 psia, sec (Ref. t_0)[1]		---	1.995	---	2.116	---	---	---	---
Propellant Utilization Valve Position, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / ---	Open / ---	Null / ---	Null / ---	Open / ---	Open / ---

Notes: [1] Data reduced from oscillogram.
[2] Component conditioning to be maintained within limits for last 15 min before engine start.
[3] Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

TABLE VII
ENGINE VALVE TIMINGS
a. Test J4-1801-39

Firing Number J4-1801-	Start																							
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
39A	0	0.127	0.110	0.450	0.128	0.250	-3.013	0.055	0.073	0.450	0.062	0.044	0.450	0.564	2.085	0.450	0.118	0.024	0.450	0.185	0.085	0.450	0.239	0.296
39B	0	0.132	0.119	0.451	0.128	0.246	-7.919	0.061	0.080	0.451	0.064	0.053	0.451	0.654	1.878	0.451	0.125	0.025	0.451	0.200	0.096	0.451	0.207	0.305
39C	0	0.131	0.118	0.450	0.132	0.255	-7.918	0.055	0.067	0.450	0.060	0.055	0.450	0.632	1.800	0.450	0.122	0.024	0.450	0.187	0.091	0.450	0.217	0.311
39D	0	0.131	0.122	0.450	0.127	0.256	-3.014	0.058	0.086	0.450	0.060	0.057	0.450	0.540	1.970	0.450	0.125	0.025	0.450	0.197	0.091	0.450	0.240	0.311
39E	0	0.131	0.122	0.449	0.128	0.256	-7.917	0.058	0.084	0.449	0.057	0.055	0.449	0.660	---	0.449	0.120	0.024	0.449	0.193	0.097	0.449	0.224	0.298
Final Sequence	0	0.089	0.096	0.449	0.126	0.243	-0.999	0.047	0.081	0.449	0.053	0.044	0.449	0.549	1.730	0.449	0.094	0.025	0.449	0.145	0.074	0.449	0.207	0.304

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
39A	32.571	0.126	0.320	32.571	0.085	0.181	32.571	0.076	0.022	32.571	0.031	0.019	32.571	0.250	0.570
39B	7.589	0.109	0.306	7.589	0.079	0.194	7.589	0.082	0.022	7.589	0.040	0.019	7.589	0.219	0.525
39C	7.589	0.102	0.320	7.589	0.081	0.192	7.589	0.084	0.022	7.589	0.038	0.025	7.589	0.223	0.549
39D	7.588	0.118	0.349	7.588	0.079	0.198	7.588	0.086	0.021	7.588	0.039	0.018	7.588	0.254	0.575
39E	1.150	0.034	0.053	1.150	0.108	0.345	1.150	0.091	0.020	1.150	0.057	0.027	1.150	0.132	0.553
Final Sequence	---	0.082	0.237	---	0.060	0.132	---	0.100	0.027	---	0.062	0.029	---	0.315	0.518

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid bas been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

TABLE VII (Continued)
b. Test J4-1801-40

Firing Number J4-1801-	Start																					
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
40A	0	0.138	0.123	0.450	0.127	0.254	-3.012	0.057	0.068	0.450	0.059	0.050	0.450	0.703	---	0.450	0.122	0.022	0.450	0.180	0.102	0.450	0.235	0.298
40AA	0	0.140	0.131	0.449	0.133	0.254	-3.002	0.057	0.084	0.449	0.049	0.051	0.449	0.680	2.109	0.449	0.121	0.026	0.449	0.180	0.092	0.449	0.235	0.303
40B	0	0.140	0.125	0.450	0.132	0.253	-7.917	0.060	0.081	0.450	0.058	0.053	0.450	0.684	1.958	0.450	0.125	0.029	0.450	0.198	0.088	0.450	0.213	0.302
40C	0	0.129	0.131	0.447	0.130	0.258	-7.916	0.058	0.071	0.447	0.059	0.051	0.447	0.580	1.890	0.447	0.128	0.029	0.447	0.201	0.109	0.447	0.235	0.300
40D	0	0.138	0.127	0.448	0.130	0.252	-7.920	0.067	0.082	0.448	0.056	0.054	0.448	0.661	1.944	0.448	0.124	0.028	0.448	0.204	0.112	0.448	0.217	0.300
Final Sequence	0	0.091	0.084	0.450	0.127	0.238	-0.997	0.048	0.079	0.450	0.051	0.044	0.450	0.548	1.733	0.450	0.095	0.027	0.450	0.144	0.077	0.450	0.202	0.295

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
40A	2.183	0.111	0.320	2.183	---	---	2.183	0.072	0.018	2.183	0.028	0.024	2.183	0.213	0.582
40AA	32.578	0.115	0.335	32.576	0.085	0.204	32.576	0.073	0.024	32.576	0.032	0.015	32.576	0.243	0.556
40B	7.590	0.107	0.325	7.580	0.075	0.196	7.590	0.081	0.020	7.590	0.038	0.020	7.590	0.218	0.488
40C	32.577	0.115	0.360	32.577	0.076	0.183	32.577	0.090	0.040	32.577	0.032	0.018	32.577	0.247	0.542
40D	7.590	0.105	0.321	7.580	0.076	0.188	7.590	0.090	0.018	7.590	0.024	0.036	7.590	0.220	0.513
Final Sequence	13.085	0.081	0.238	13.085	0.061	0.129	13.085	0.099	0.029	13.085	0.061	0.029	13.085	0.213	0.626

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

TABLE VII (Concluded)
c. Test J4-1801-41

Firing Number J4-1801-	Start																					
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, aec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, aec	Valve Opening Time, aec	Time of Closing Signal	Valve Delay Time, aec	Valve Closing Time, sec
41A	0	0.128	0.111	0.448	0.129	0.241	-3.019	0.054	0.066	0.448	0.058	0.048	0.448	0.566	1.952	0.448	0.118	0.022	0.448	0.184	0.081	0.448	0.221	0.295
41B	0	0.135	0.118	0.449	0.130	0.246	-7.917	0.055	0.090	0.449	0.060	0.048	0.449	0.550	1.929	0.449	0.127	0.023	0.449	0.198	0.092	0.449	0.220	0.313
41C	0	0.136	0.124	0.449	0.135	0.262	-3.020	0.052	0.103	0.449	0.062	0.052	0.449	0.557	---	0.449	0.126	0.026	0.449	0.195	0.092	0.449	0.237	0.305
41D	0	0.135	0.123	0.448	0.129	0.264	-7.917	0.060	0.094	0.448	0.060	0.051	0.448	0.588	---	0.448	0.122	0.024	0.448	0.190	0.093	0.448	0.245	0.308
Final Sequence	0	0.089	0.095	0.450	0.129	0.238	-1.000	0.046	0.080	0.450	0.051	0.046	0.450	0.570	1.740	0.450	0.095	0.025	0.450	0.143	0.080	0.450	0.209	0.297

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, aec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
41A	32.575	0.104	0.289	32.575	0.079	0.178	32.575	0.073	0.024	32.575	0.031	0.017	32.575	0.221	0.374
41B	7.591	0.104	0.315	7.591	0.076	0.184	7.591	0.082	0.019	7.591	0.040	0.019	7.591	0.220	0.428
41C	1.263	0.112	0.334	1.263	---	---	1.263	0.098	0.024	1.263	0.054	0.028	1.263	0.139	0.355
41D	1.258	0.110	0.344	1.258	---	---	1.258	0.098	0.023	1.258	0.054	0.028	1.258	0.144	0.416
Final Sequence	7.469	0.078	0.236	7.469	0.060	0.131	7.469	0.096	0.031	7.469	0.059	0.031	7.469	0.216	0.638

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final aequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

TABLE VIII
ENGINE VIBRATION AND AUGMENTED SPARK IGNITER PROPELLANT LINE STRAIN LEVELS
a. Firings J4-1801-40A and J4-1801-40AA

Parameter	Firing J4-1801-40A					Firing J4-1801-40AA						
	At Engine Start	At t_0	At Dome Prime	At t_0 + 2.12 sec	At c/o + 2.5 sec	At Engine Start	At t_0	At Dome Prime	At t_0 + 2.1 sec	At t_0 + 10 sec	At t_0 + 30 sec	At c/o + 4.5 sec
UTCD-1[1]	---	---	750	100	---	---	---	650	50	45	45	---
UTCD-2	---	---	675	50	---	---	---	625	45	40	40	---
UFPR	---	---	Invalid	Invalid	---	---	---	Invalid	Invalid	Invalid	Invalid	---
UOPR	---	---	200	150	---	---	---	325	200	90	65	---
UASIF-1	---	---	Invalid	Invalid	---	---	---	Invalid	Invalid	Invalid	Invalid	---
UASIF-2	---	---	325	100	---	---	---	345	90	45	45	---
UOTBV	---	---	275	75	---	---	---	335	70	95	90	---
UMFV-1	---	---	Invalid	Invalid	---	---	---	Invalid	Invalid	Invalid	Invalid	---
UMFV-2	---	---	200	50	---	---	---	250	45	40	90	---
UASIV-1	---	---	Invalid	Invalid	---	---	---	Invalid	Invalid	Invalid	Invalid	---
SGOASI-1[2]	-540 ± 75	-390	-60 ± 290	-120	-100	-540	-412	-45 ± 365	-15 ± 85	-155	-125	-185 ± 60
SGOASI-2	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
SGOASI-3	-15 ± 40	-30	-25 ± 210	25 ± 104	-160	0	-25	-40 ± 475	5 ± 80	-5 ± 90	30 ± 70	-110 ± 45
SGFASI-1	15 ± 40	-25	-25 ± 240	-25	520	26	15	-130 ± 500	-145	170	-115	-195 ± 65
SGFASI-2	95 ± 95	50	460 ± 930	1210	1235	490	235	675 ± 720	1070	1000	955	770 ± 115
SGFASI-3	25 ± 50	75	325 ± 250	400 ± 290	250	85	240	465 ± 355	450 ± 245	350	235 ± 105	255 ± 35
SGFASI-4	225 ± 50	220	510 ± 220	700 ± 750	630	290	435	655 ± 325	715 ± 500	920 ± 195	1190 ± 265	740 ± 65

[1] U denotes accelerometer; data tabulated are in composite g peak-to-peak amplitude to 5-kHz maximum frequency response.

[2] SG denotes strain gage; data tabulated are indicated microinches/inch oscillatory strain levels.

[3] Data are from the FM system transcribed to oscillogram time-history records at 8-in./sec oscillograph speed.

TABLE VIII (Continued)
b. Firings J4-1801-40C and J4-1801-40D

Parameter	Firing J4-1801-40C						Firing J4-1801-40D					
	At Engine Start	At t_0	At Dome Prime	At t_0 + 2.12 sec	At t_0 + 8 sec	At t_0 + 30 sec	At Engine Start	At t_0	At Dome Prime	At t_0 + 1.89 sec	At t_0 + 6 sec	At c/o + 4.5 sec
UTCD-1[1]	---	---	625	45	45	75	---	---	700	60	55	---
UTCD-2	---	---	600	45	40	40	---	---	650	45	45	---
UFPR	---	---	Invalid	Invalid	Invalid	Invalid	---	---	Invalid	Invalid	Invalid	---
UOPR	---	---	300	95	100	60	---	---	200	150	105	---
UASIF-1	---	---	325	160	155	200	---	---	300	Invalid	Invalid	---
UASIF-2	---	---	310	45	50	50	---	---	295	50	50	---
UOTBV	---	---	385	100	150	100	---	---	350	100	70	---
UMFV-1	---	---	Invalid	Invalid	Invalid	Invalid	---	---	Invalid	Invalid	Invalid	---
UMFV-2	---	---	305	30	40	50	---	---	305	45	40	---
UASIV-1	---	---	Invalid	Invalid	Invalid	Invalid	---	---	Invalid	Invalid	Invalid	---
SGOASI-1[2]	-465 ± 70	-95 ± 60	-30 ± 185	-45 ± 85	75 ± 75	45 ± 95	-340 ± 75	-75 ± 75	-15 ± 130	-30 ± 75	-155 ± 95	125 ± 75
SGOASI-2	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
SGOASI-3	35 ± 40	-50 ± 35	-40 ± 280	-15 ± 55	20 ± 60	80 ± 95	-35 ± 45	-105 ± 25	-50 ± 260	-20 ± 85	-33 ± 60	-115 ± 45
SGFASI-1	65 ± 60	65 ± 50	25 ± 430	50 ± 60	-26 ± 65	0 ± 70	65 ± 50	50 ± 50	25 ± 155	-195 ± 70	25 ± 65	-235 ± 50
SGFASI-2	655 ± 125	655 ± 130	700 ± 395	1120 ± 95	1190 ± 115	1120 ± 165	605 ± 115	725 ± 95	885 ± 490	1190 ± 140	1725 ± 115 [4]	1350 ± 70[4]
SGFASI-3	300 ± 40	540 ± 50	690 ± 120	575 ± 75	600 ± 115	275 ± 75	125 ± 50	200 ± 65	485 ± 182	475 ± 195	400 ± 75	0 ± 35
SGFASI-4	410 ± 55	620 ± 40	790 ± 215	705 ± 95	850 ± 75	1065 ± 85	180 ± 50	340 ± 75	725 ± 265	740 ± 400	800 ± 75	350 ± 65

[1] U denotes accelerometer; data tabulated are in composite g peak-to-peak amplitude to 5-kHz maximum frequency response.
[2] SG denotes strain gage; data tabulated are indicated microinches/inch oscillatory strain levels.
[3] Data are from the FM system transcribed to oscillogram time-history records at 8-in./sec oscillograph speed.
[4] Questionable validity.

TABLE VIII. (Concluded)

c. Firings J4-1801-41A and J4-1801-41B

Parameter	Firing J4-1801-41A							Firing J4-1801-41B						
	At Engine Start	At t_0	At Dome Prime	At t_0 + 1.7 sec	t_0 + 12 sec	At t_0 + 30 sec	At c/o + 4.5 sec	At Engine Start	At t_0	At Dome Prime	At t_0 + 2.0 sec	At t_0 + 6 sec	At c/o + 4.5 sec
UTCD-1[1]	---	---	550	45	50	50	---	---	---	600	---	50	---
UTCD-2	---	---	525	30	40	45	---	---	---	495	---	45	---
UFPR	---	---	250	Invalid	Invalid	Invalid	---	---	---	Invalid	Invalid	Invalid	---
UOPR	---	---	315	160	145	75	---	---	---	310	---	140	---
UASIF-1	---	---	Invalid	Invalid	Invalid	Invalid	---	---	---	Invalid	---	Invalid	---
UASIF-2	---	---	260	65	80	75	---	---	---	255	---	50	---
UOTBV	---	---	360	65	95	100	---	---	---	375	---	75	---
UMFV-1	---	---	Invalid	Invalid	Invalid	Invalid	---	---	---	Invalid	---	Invalid	---
UMFV-2	---	---	240	45	75	60	---	---	---	260	---	65	---
UASIV-1	---	---	Invalid	Invalid	Invalid	Invalid	---	---	---	Invalid	Invalid	Invalid	---
SGOASI-1[2]	262 ± 75	-305	-75 ± 225	-30 ± 65	-45 ± 75	-85 ± 75	-60 ± 75	250 ± 60	-75 ± 60	-60 ± 90	-30 ± 75	-30 ± 65	-30 ± 60
SGOASI-2	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
SGOASI-3	95 ± 35	-65	30 ± 145	20 ± 75	80 ± 30	105 ± 40	290 ± 30	100	-320 ± 25	65 ± 410	45 + 80	65 ± 55	-10
SGFASI-1	205 ± 50	15	190 ± 350	105 ± 50	25 ± 50	0 ± 65	65 ± 65	205 ± 40	245 ± 65	260 ± 235	280 ± 50	165 ± 50	-15 ± 60
SGFASI-2	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
SGFASI-3	120 ± 50	615	630 ± 300	590 ± 75	340 ± 50	145 ± 75	50 ± 50	135 ± 60	325 ± 60	620 ± 165	565 ± 120	480 ± 60	-50 ± 50
SGFASI-4	130 ± 50	750	855 ± 350	860 ± 560	835 ± 130	950 ± 105	785 ± 60	165 ± 50	775 ± 60	785 ± 185	785 ± 405	785 ± 70	340 ± 35

[1] U denotes accelerometer; data tabulated are in composite g peak-to-peak amplitude to 5-kHz maximum frequency response.
[2] SG denotes strain gage; data tabulated are indicated microinches/inch oscillatory strain levels.
[3] Data are from the FM system transcribed to oscillogram time-history records at 8-in./sec oscillograph speed.

TABLE IX
TYPICAL AUGMENTED SPARK IGNITER PROPELLANT LINE STRAIN OSCILLATION SPECTRA

Parameter	Firing J4-1801-41A				Firing J4-1801-41B			
	At t_0 + 12 sec		At t_0 + 30 sec		At t_0 - 3 sec		At t_0 + 12 sec	
	Frequency, Hz	Relative Power Spectral Density, g^2/Hz	Frequency, Hz	Relative Power Spectral Density, g^2/Hz	Frequency, Hz	Relative Power Spectral Density, g^2/Hz	Frequency, Hz	Relative Power Spectral Density, g^2/Hz
SGOASI-1					3.0	Small	3.0	Small
	2.5	Small	2.5	Small	18.0	Small		
	32.0	Small	32.0	Small	25.0	Small		
	82.0	Large	62.0	Large	33.0	Small	33.0	Large
	187.0	Large	187.0	Large	63.0	Large	62.0	Large
	308.0	Large	306.0	Large	184.0	Large	183.0	Large
			421.0	Small			304.0	Large
	467.0	Small	871.0	Small			424.0	Small
							458.0	Large
							907.0	Large
SGOASI-3					4.0	Large	5.0	Small
	2.5	Small	3.0	Small			14.0	Small
	14.0	Small	14.0	Small	19.0	Small	19.0	Small
	33.0	Small	33.0	Small	26.0	Small		
	63.0	Small	62.0	Small	34.0	Large	34.0	Large
			80.0	Small	64.0	Small	64.0	Large
	467.0	Large	464.0	Large	184.0	Small	184.0	Small
	670.0	Small	680.0	Large			462.0	Large
			873.0	Small			910.0	Large
	930.0	Small	933.0	Small				
SGFASI-1	2.5	Small	2.5	Large	-3.0	Large	2.5	Large
	11.0	Large	12.5	Small			11.0	Small
	17.0	Small			18.0	Small		
	32.0	Small	33.0	Large	32.0	Large		
	62.0	Small	63.0	Small	63.0	Small		
			182.0	Small			460.0	Large
	470.0	Large	470.0	Small			527.0	Small
SGFASI-3	2.5	Large	2.5	Large	4.0	Large	4.0	Large
	32.0	Small	33.0	Small	13.0	Small		
	83.0	Small	64.0	Small	19.0	Small		
			124.0	Small	33.0	Small	33.0	Small
			380.0	Large	64.0	Small	64.0	Small
	402.0	Large	402.0	Large			375.0	Large
	468.0	Small					458.0	Large
	871.0	Large	667.0	Large			672.0	Large
SGFASI-4	2.0	Small	2.5	Small	2.0	Large	2.0	Large
	63.0	Large	67.0	Large	18.0	Small		
	123.0	Small	127.0	Small	25.0	Small		
	184.0	Small	188.0	Small	62.0	Large	63.0	Large
	407.0	Large	401.0	Large	123.0	Small	125.0	Small
	465.0	Large	463.0	Large	183.0	Small	184.0	Small
	922.0	Large	923.0	Large	244.0	Small		
							404.0	Large
							457.0	Large
							916.0	Large

TABLE X
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		39A		40AA		40C		41A	
		Site	Normalized	Site	Normalized	Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb_f	235,080	231,878	241,292	238,794	241,062	239,026	230,813	227,733
	Chamber Pressure, psia	793.3	778.5	814.1	801.8	813.4	802.8	778.5	764.8
	Mixture Ratio	5.425	5.453	5.464	5.479	5.537	5.534	5.333	5.342
	Fuel Weight Flow, lb_m/sec	87.04	85.16	87.85	86.39	87.08	86.00	85.66	84.09
	Oxidizer Weight Flow, lb_m/sec	472.22	464.44	479.98	473.38	482.11	475.88	456.79	449.17
	Total Weight Flow, lb_m/sec	559.26	549.60	567.83	559.77	569.18	561.88	542.45	533.26
Thrust Chamber Performance	Mixture Ratio	5.624	5.657	5.666	5.685	5.747	5.747	5.535	5.547
	Total Weight Flow, lb_m/sec	551.91	547.35	560.34	552.36	561.64	554.40	535.25	526.14
	Characteristic Velocity, ft/sec	7867.9	7857.2	7952.9	7949.3	7928.2	7929.9	7961.3	7956.6
Fuel Turbopump Performance	Pump Efficiency, percent	72.8	72.8	72.2	72.3	72.8	72.8	72.6	72.6
	Pump Speed, rpm	27,688	27,440	28,257	28,059	28,089	27,923	27,575	27,361
	Turbine Efficiency, percent	62.5	62.3	63.8	63.6	63.0	62.9	63.6	63.5
	Turbine Pressure Ratio	7.33	7.32	7.12	7.12	7.13	7.13	7.28	7.28
	Turbine Inlet Temperature, °F	1256	1240	1260	1245	1246	1229	1166	1149
	Turbine Weight Flow, lb_m/sec	7.35	7.25	7.49	7.41	7.54	7.48	7.20	7.11
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.4	80.4	80.4	80.4	80.4	80.4	80.2	80.2
	Pump Speed, rpm	8782	8706	8965	8898	8988	8916	8641	8563
	Turbine Efficiency, percent	50.5	50.3	50.5	50.3	50.9	50.8	50.5	50.3
	Turbine Pressure Ratio	2.63	2.63	2.63	2.63	2.63	2.63	2.60	2.60
	Turbine Inlet Temperature, °F	799	788	803	792	792	779	737	725
	Turbine Weight Flow, lb_m/sec	6.39	6.30	6.62	6.55	6.67	6.61	6.18	6.10
Gas Generator Performance	Mixture Ratio	0.973	0.964	0.976	0.966	0.967	0.957	0.920	0.910
	Chamber Pressure, psia	717.2	706.1	731.1	722.0	735.0	727.1	692.9	682.8

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec, except as noted.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for tests J4-1801-39 through -41 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EASIOV	Augmented Spark Igniter Oxidizer Valve Open		On/Off	x		x		
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x				
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-1 SAM	Fuel Flow Stall Approach Monitor		0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x(1)	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x[1]			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCBO	Constant Bleed Orifice		0 to 50	x				
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x[1]	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ[1]	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x[1]			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI[2]	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				x
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x		x		x
PFPI-2	Fuel Pump Inlet		0 to 200	x		x		x
PFPI-3	Fuel Pump Inlet		0 to 200		x			
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFPPSD-2[2]	Fuel Pump Primary Seal Drain		0 to 100	x				
PFPS-1P[1]	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTSP-1[2]	Fuel Turbine Seal Purge Line		0 to 100	x				
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PGGOC[2]	Gas Generator Opening Control		0 to 500	x				
PGGVB[2]	Gas Generator Valve Body		0 to 50	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
PNET-1[3]	Nozzle Exit Total		0 to 5	x		x		
PNET-2[3]	Nozzle Exit Total		0 to 5	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure (Continued)		Percent Open					
POBSC(2)	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV(2)	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x(1)			
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30, 000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15, 000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12, 000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15, 000	x				
	Strain		μin. /in.					
SGFASI-1(3)	Augmented Spark Igniter Fuel Line		±1500		x			
SGFASI-2(3)	Augmented Spark Igniter Fuel Line		±1500		x			
SGFASI-3(3)	Augmented Spark Igniter Fuel Line		±1500		x			
SGFASI-4(3)	Augmented Spark Igniter Fuel Line		±1500		x			
SGOASI-1(3)	Augmented Spark Igniter Oxidizer Line		±1500		x			
SGOASI-2(3)	Augmented Spark Igniter Oxidizer Line		±1500		x			
SGOASI-3(3)	Augmented Spark Igniter Oxidizer Line		±750		x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ[1]	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1[1]	Augmented Spark Igniter Line		-300 to +100	x				
TFASIL-2[1]	Augmented Spark Igniter Line		-300 to +100	x				
TFASIL-3[1]	Augmented Spark Igniter Line		-300 to +100	x				
TFASIL-4[3]	Augmented Spark Igniter Line		-425 to +500	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD[2]	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFPPSD-1[2]	Fuel Pump Primary Seal Drain		-425 to +100	x				
TFPSP-1[2]	Pump Seal Purge		-425 to +100	x				
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1[2]	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-5[2]	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6[2]	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7[2]	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to ±1400	x			x	
TFTO[2]	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x	x	
TGGVRS	Gas Generator Valve Retaining Screw		-100 to +100	x			x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures (Continued)		°F					
THET-1P	Helium Tank	NNTI	-350 to +100	x				x
TMFV-1[2]	Main Fuel Valve		-100 to +300	x				
TMFV-2[2]	Main Fuel Valve		-100 to +300	x				
TNODP	Liquid Oxygen Dome Purge		0 to -300	x				
TOASIL-1[3]	Augmented Spark Igniter Oxidizer Line Skin		-425 to +500	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A[1]	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4[1]	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x[1]	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle Throat		-300 to +100	x				
TPCC[1]	Prechill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPNET-1[3]	Nozzle Total Pressure Transducer Surface		-350 to +500	x				
TSC2-A1[2]			-300 to +100	x				
TSC2-A2[2]			-300 to +100	x				
TSC2-A3[2]			-300 to +100	x				
TSC2-A4[2]			-300 to +100	x				
TSC2-A5[2]			-300 to +100	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-3[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-4[2]	Thrust Chamber Skin		-300 to +500					
TSC2-5[2]	Thrust Chamber Skin		-300 to +500	x				

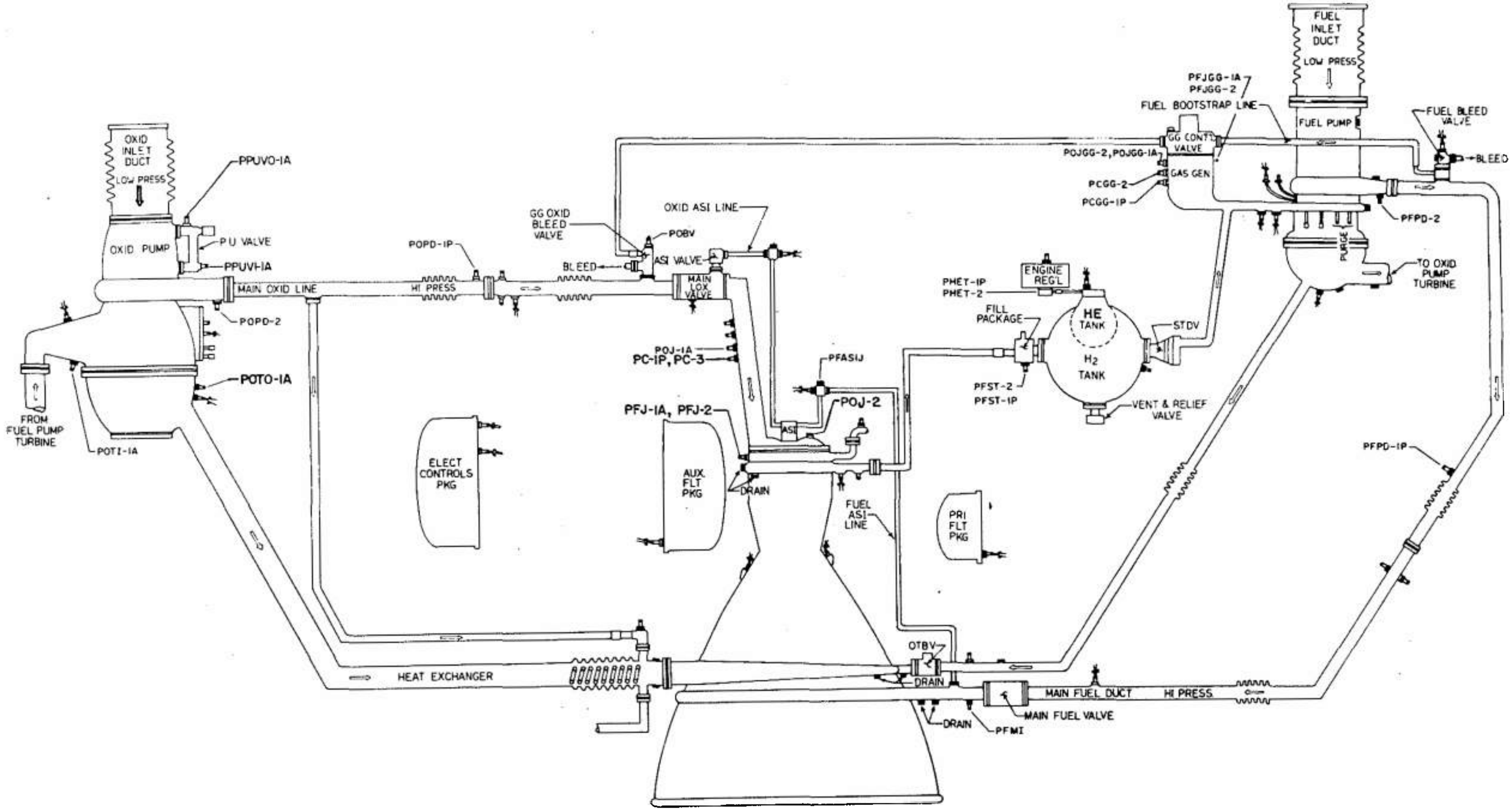
TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures (Continued)		°F					
TSC2-6[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-7[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-8[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-9[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-10[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-11[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-15[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-16[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-19[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-22[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-23[2]	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1[2]	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x			x	
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x			x	
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTC-2	Thrust Chamber Jacket (Control)	CS1A	-425 to +500	x				
TTCEP-1[2]	Thrust Chamber Exit		-425 to +500	x				
TTPP	Turbopump Purge		-150 to +150	x			x	
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g's					
UASIF-1[3]	Augmented Spark Igniter Fuel Orifice Block		±150		x			
UASIV-1[3]	Augmented Spark Igniter Oxidizer Valve		±150		x			
UASIV-2[3]	Augmented Spark Igniter Oxidizer Valve		±150		x			
UFPR	Fuel Pump Radial 90 deg		±300		x	x		
UMFV-1[3]	Main Fuel Valve		±150		x			
UMFV-2[3]	Main Fuel Valve		±150		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			

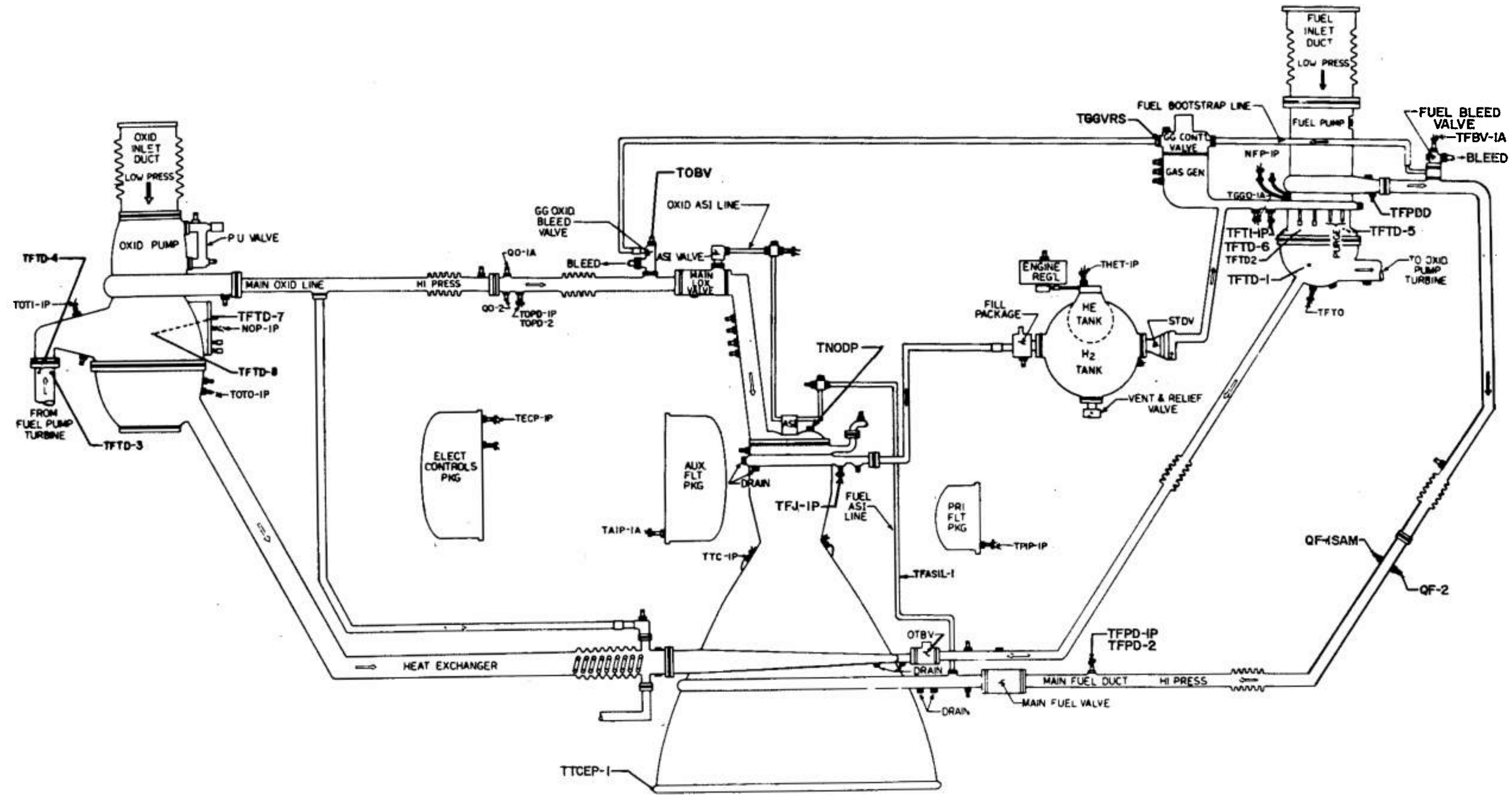
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-sadic	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Vibrations (Continued)		g's					
UOTBV-1(3)	Oxidizer Turbine Bypass Valve		±150		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-4	Thrust Chamber Dome		±500		x(1)	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

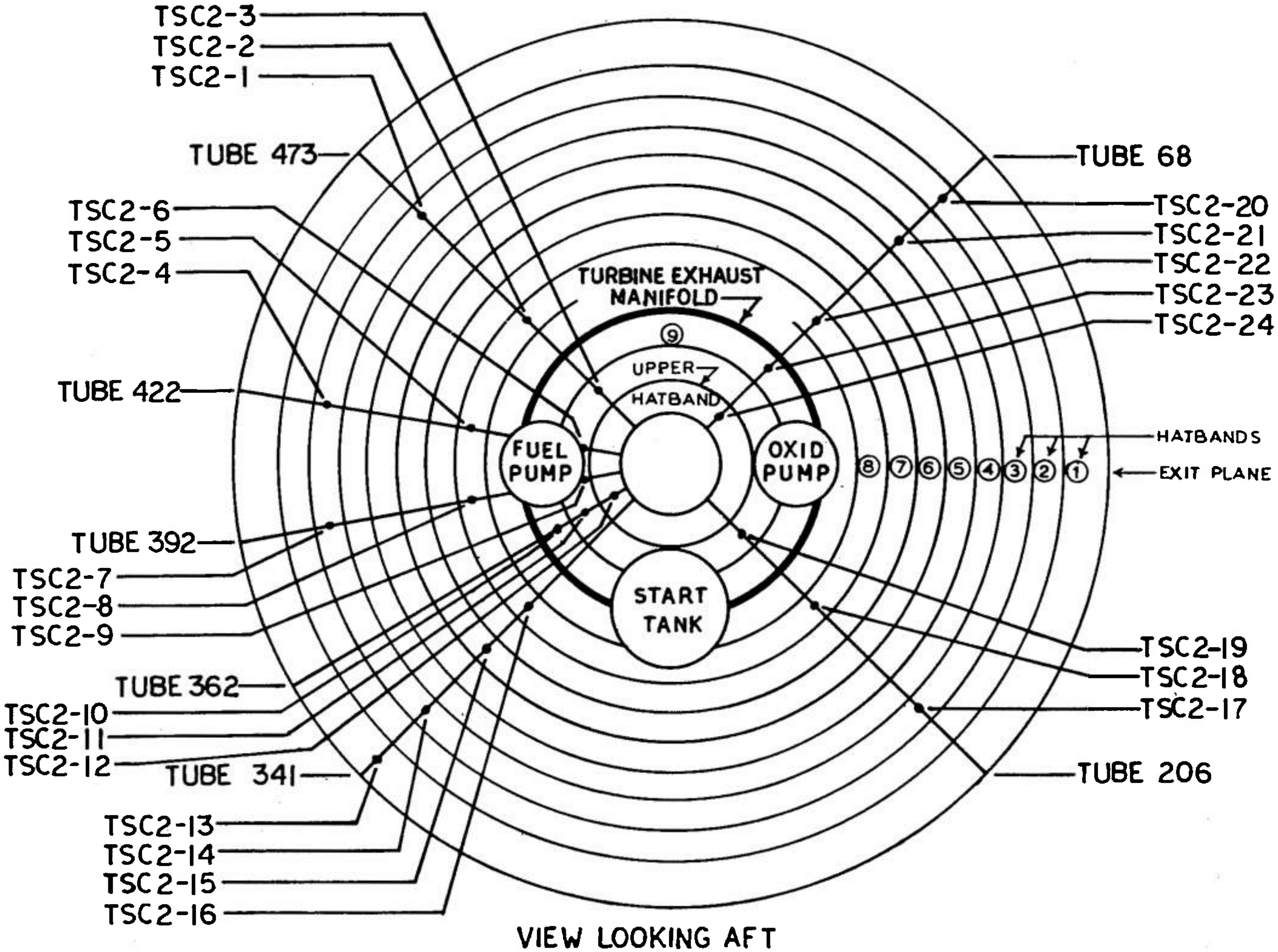
Notes: (1)Used on test 39 only.
(2)Not used on test 40.
(3)Used after test 39.



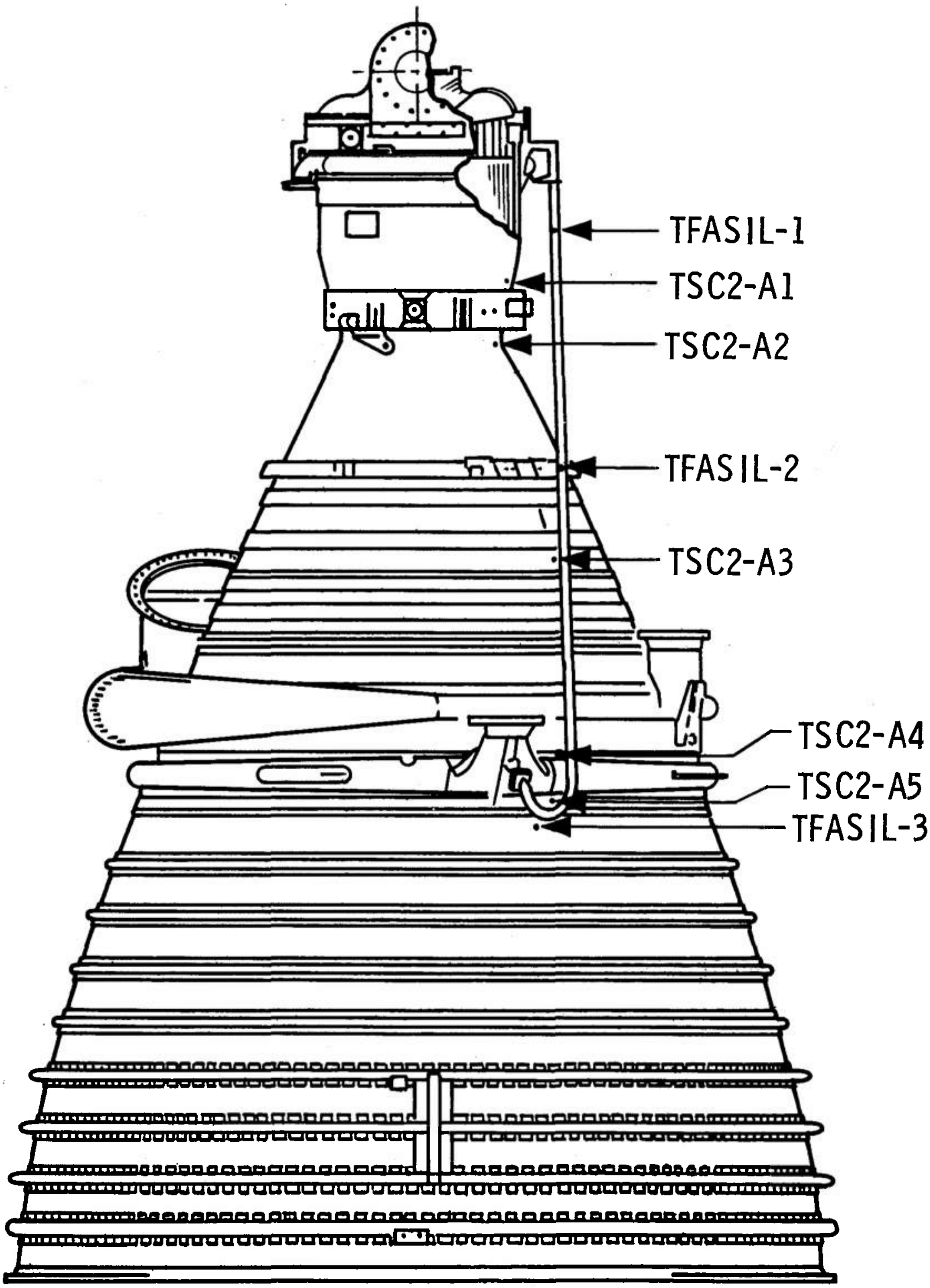
a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations



b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued



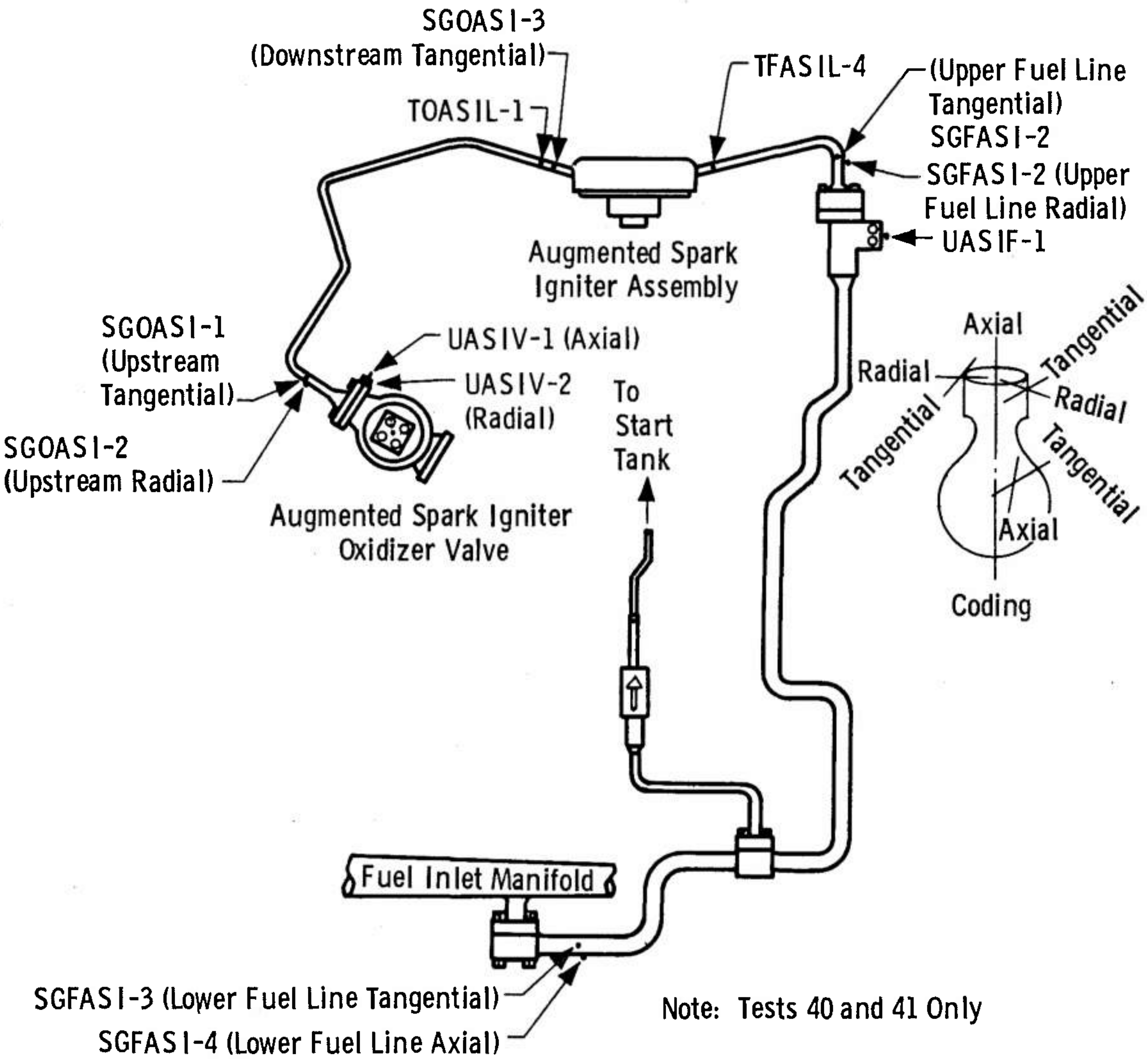
c. Thrust Chamber
Fig. III-1 Continued



Note: Test 39 Only

d. Thrust Chamber and Augmented Spark Igniter Fuel Supply Line

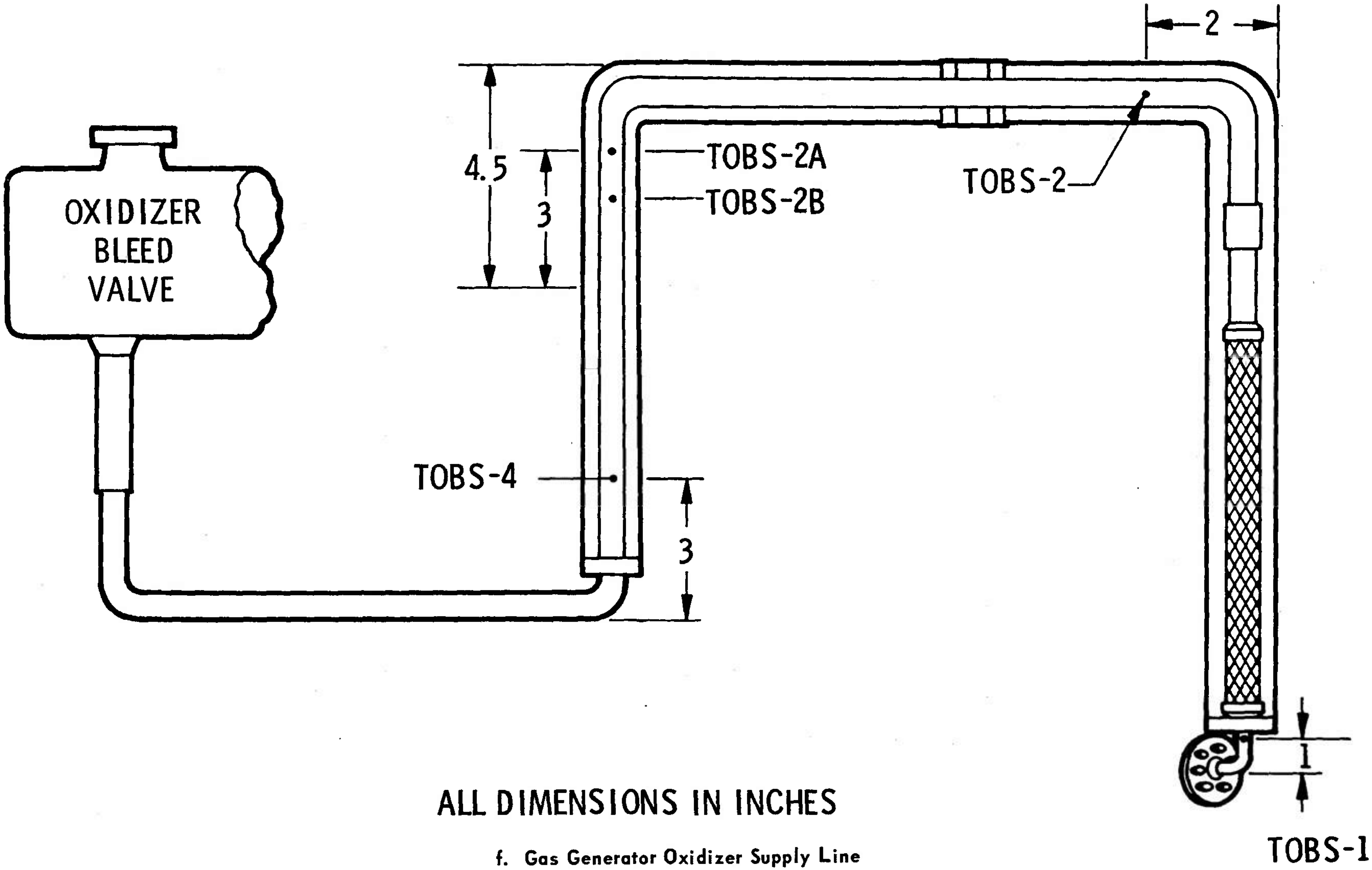
Fig. III-1 Continued



Note: Tests 40 and 41 Only

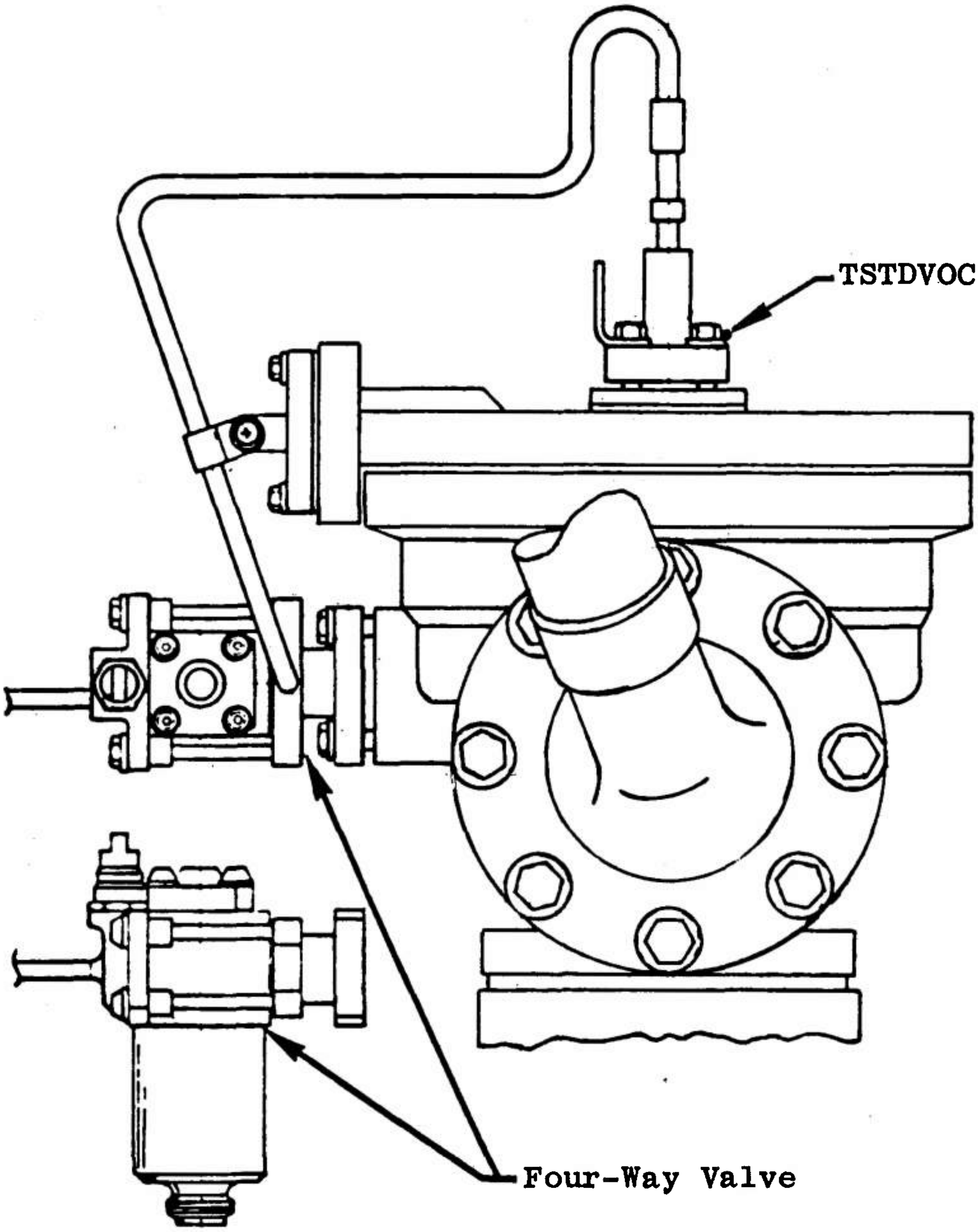
e. Augmented Spark Igniter Assembly

Fig. III-1 Continued

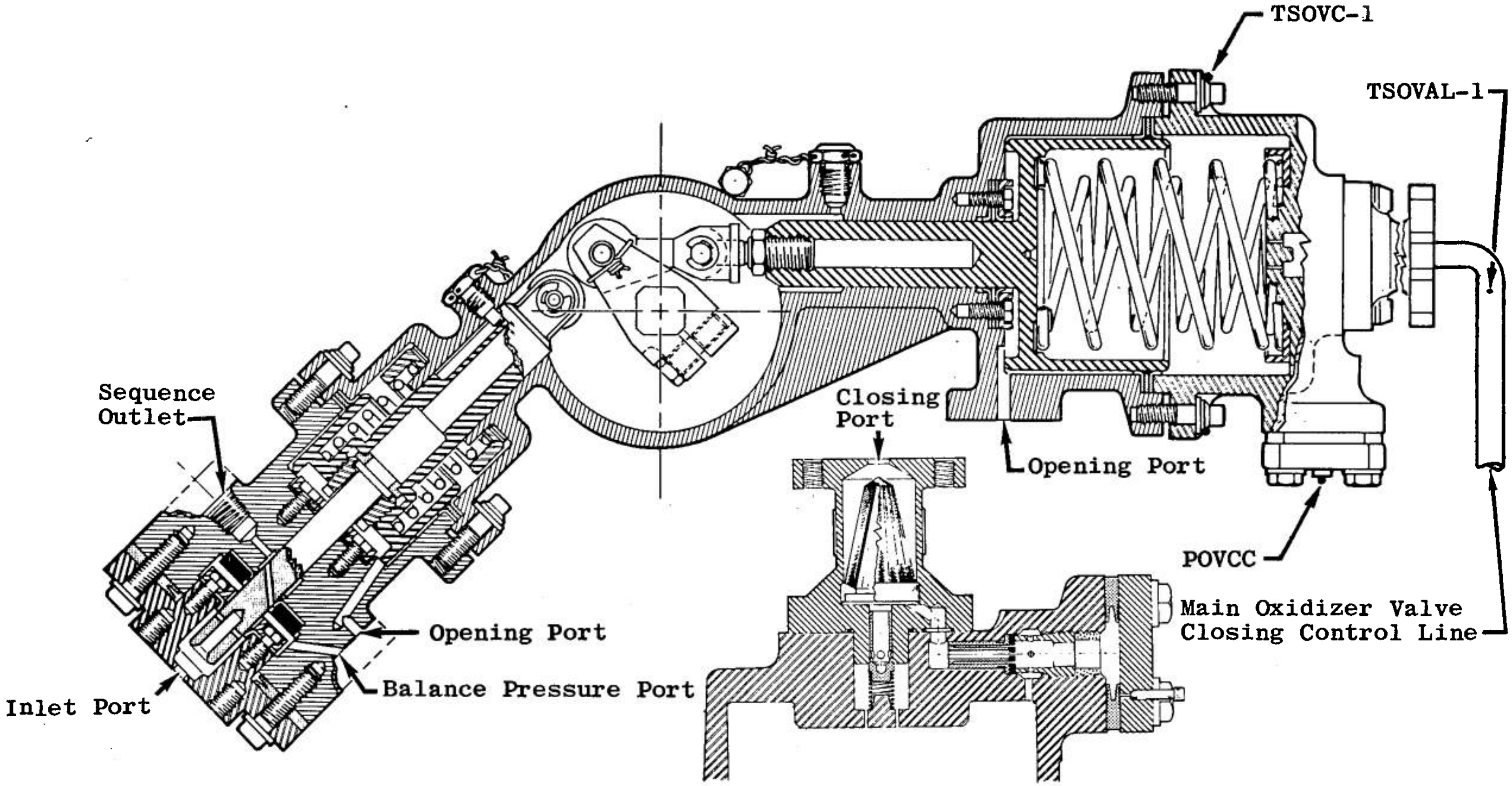


f. Gas Generator Oxidizer Supply Line

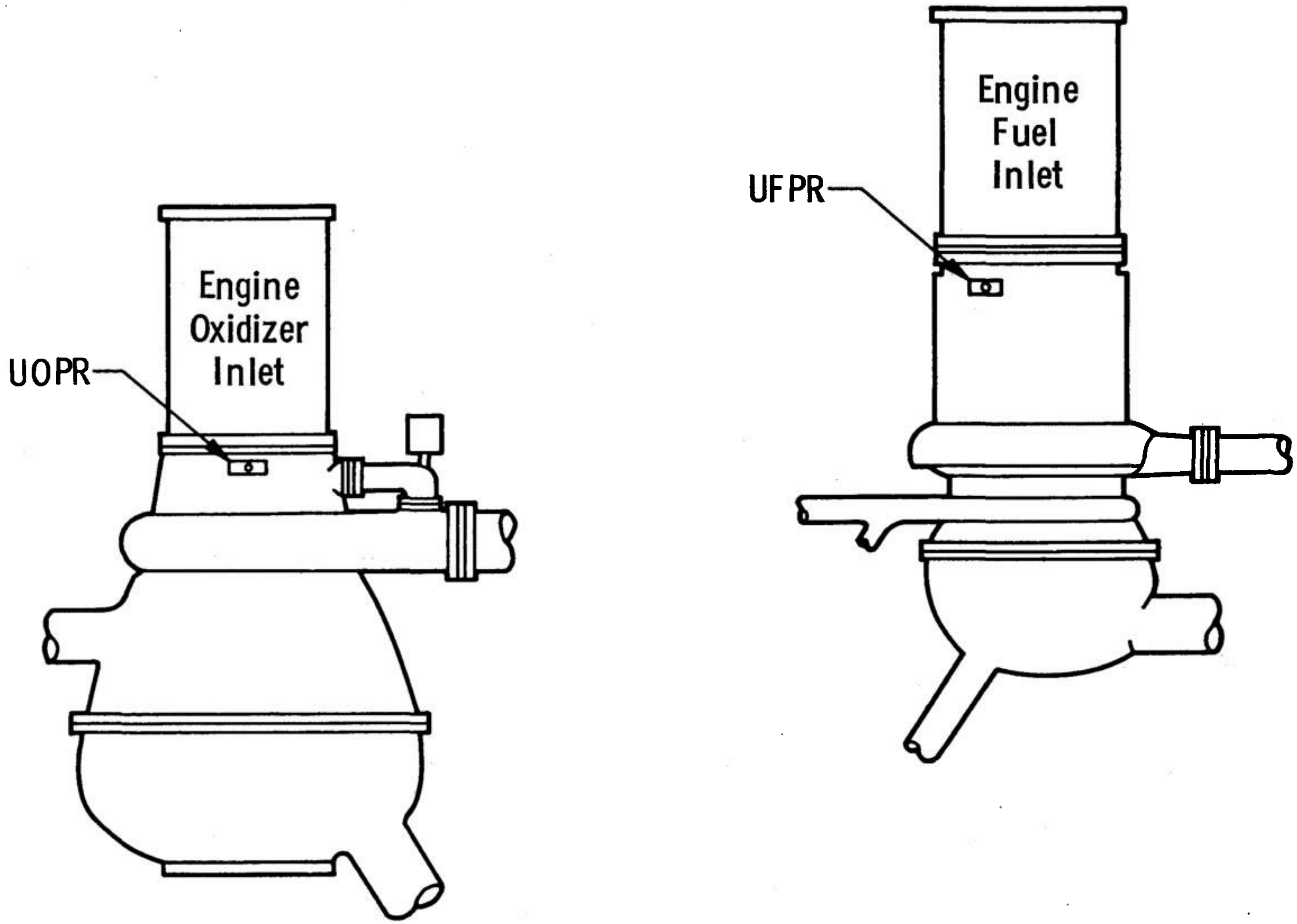
Fig. III-1 Continued



g. Start Tank Discharge Valve
Fig. III-1 Continued

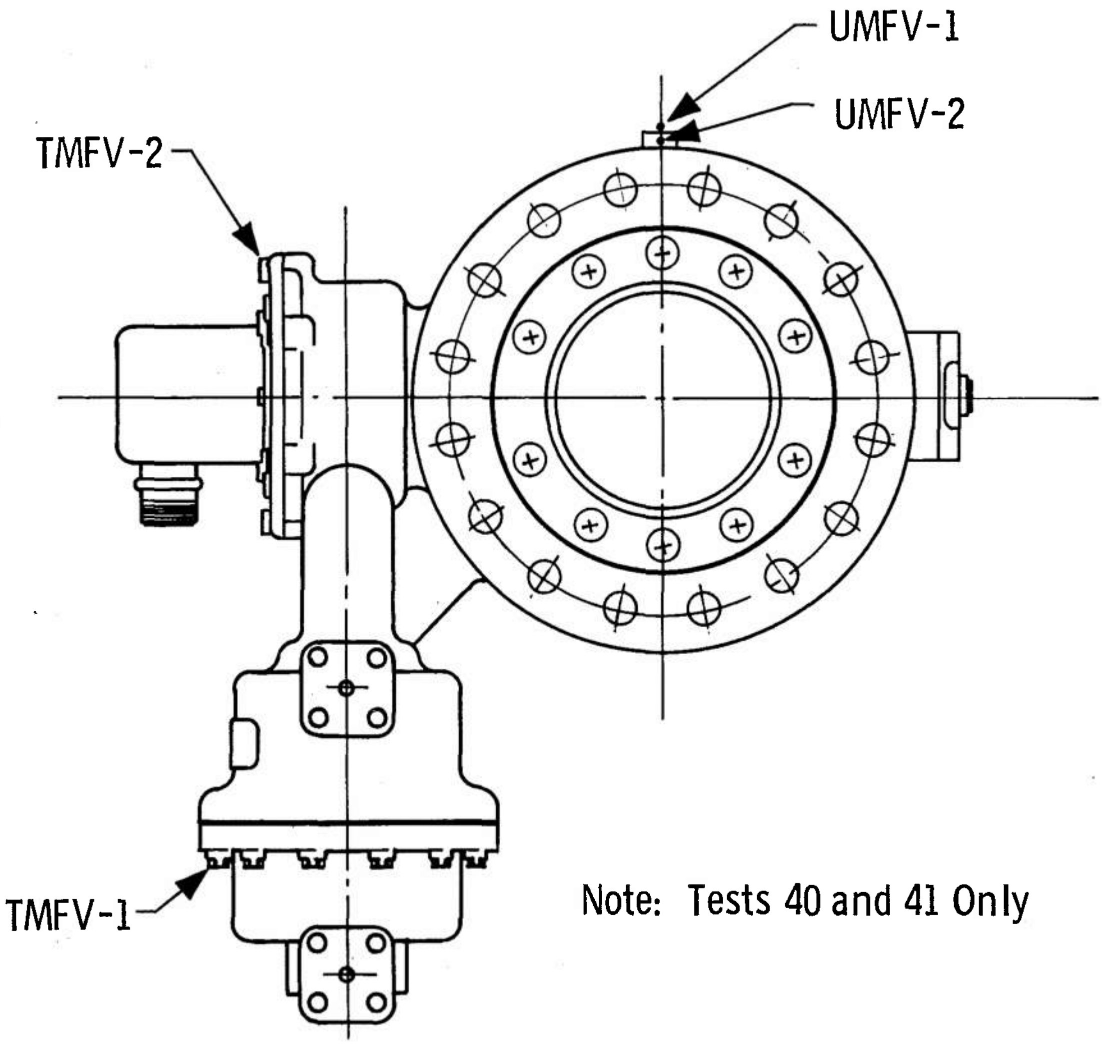


h. Main Oxidizer Valve
Fig. III-1 Continued

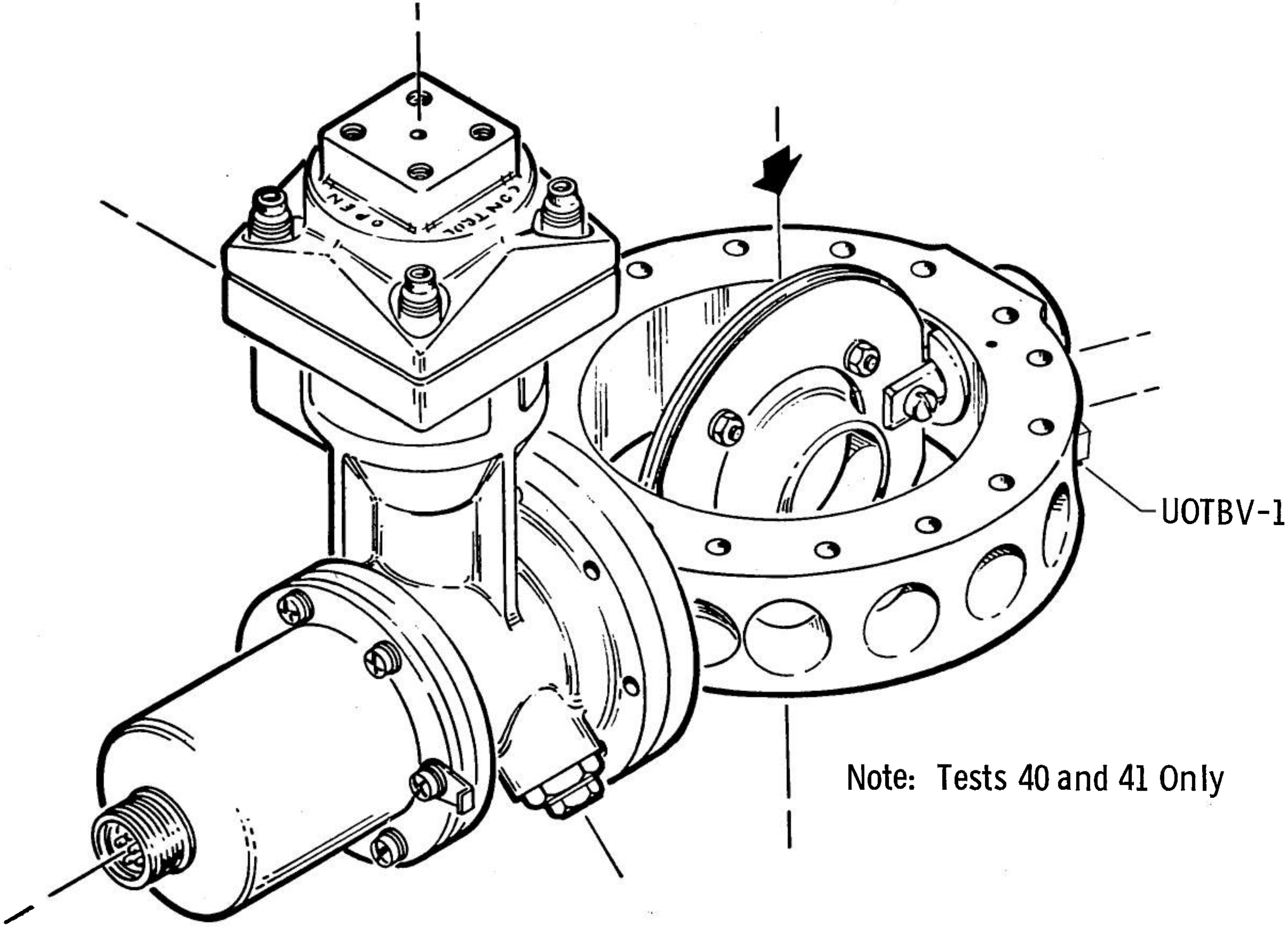


View of Engine Looking North

i. Engine Inlets
Fig. III-1 Continued



j. Main Fuel Valve
Fig. III-1 Continued



k. Oxidizer Turbine Bypass Valve Accelerometer
Fig. III-1 Concluded

APPENDIX IV
AUGMENTED SPARK IGNITER CONFIGURATION SUMMARY

During the subject test series the new augmented spark igniter propellant lines were instrumented for temperature, strain, and vibration measurements with no provisions for pressure drop (or flow rate) measurements. Before installation on engine S/N J-2047, the new propellant supply lines (tests 40 and 41) were calibrated to give the desired flow rate of hydrogen matched to the oxidizer flow rate that is provided by a 0.125-in.-diam oxidizer line orifice. Calibration was performed in "pit" tests under the following conditions.

Augmented spark igniter fuel inlet pressure, 1205 ± 30 psia
Augmented spark igniter oxidizer inlet pressure, 1010 ± 30 psia
Simulated main chamber pressure, 780 ± 30 psia
Nominal augmented spark igniter mixture ratio, 0.485 ± 0.03

Note, these conditions duplicated engine main-stage operating levels at 5.5 engine mixture ratio. Actual mixture ratios obtained for the augmented spark igniter lines installed on engine S/N J-2047 for tests 40 and 41 were as follows:

Augmented Spark Igniter* Oxidizer	Augmented Spark Igniter Fuel	M/R	Test Effectivity
0.125 in.	0.263 in.	0.556	40
0.125 in.	0.277 in.	0.467	(Not Tested)
0.125 in.	0.302 in.	0.361	41

Hence, the test 40 firings tested a minimum extreme mixture ratio condition varying S-IVB starting parameters at maximum and minimum extreme target conditions, and the test 41 firings tested a maximum extreme mixture ratio condition again with maximum and minimum S-IVB starting parameter variations. Deletion of the flexible bellows sections in the augmented spark igniter fuel lines necessitated the inclusion of an in-line orifice to obtain the same fuel line flow rate as the original configuration lines. However, the original-configuration lines with bellows sections were subject to small differences in manufacturing tolerances which allowed significant differences in augmented spark igniter mixture ratio from engine to engine. This variation in fuel flow for the oxidizer flow provided by 0.125-in.-diam oxidizer line orifice is reflected in the variation of fuel line orificing over the range from 0.263 to 0.302 in. for the modified fuel line. Thus, the firings made

*Data provided by engine manufacturer's representatives.

on engine S/N J-2047 represented limit-test integrity verifications primarily related to proving safe and reliable starting of the engine at simulated altitude conditions.

Several different oxidizer line configurations under the Engineering Change Proposal 575 modification have been tested on engine S/N J-2047 in the AEDC program varying oxidizer orifice location in the line and varying oxidizer orifice sizes with the augmented spark igniter fuel line configuration shown in Fig. IV-1, which incorporated a fuel line block. Augmented spark igniter oxidizer orifice sizes were varied from 0.110- to 0.150-in. diameter on engine S/N J-2052 in the original configuration shown in Fig. IV-1, for reference. The ECP 575 oxidizer line configuration (refer to Fig. 5) was flown on the vehicle AS-502 J-2 engines (Ref. 3).

Note: See Article 4.3 and Ref. 7 for discussion or data acquired using this configuration.

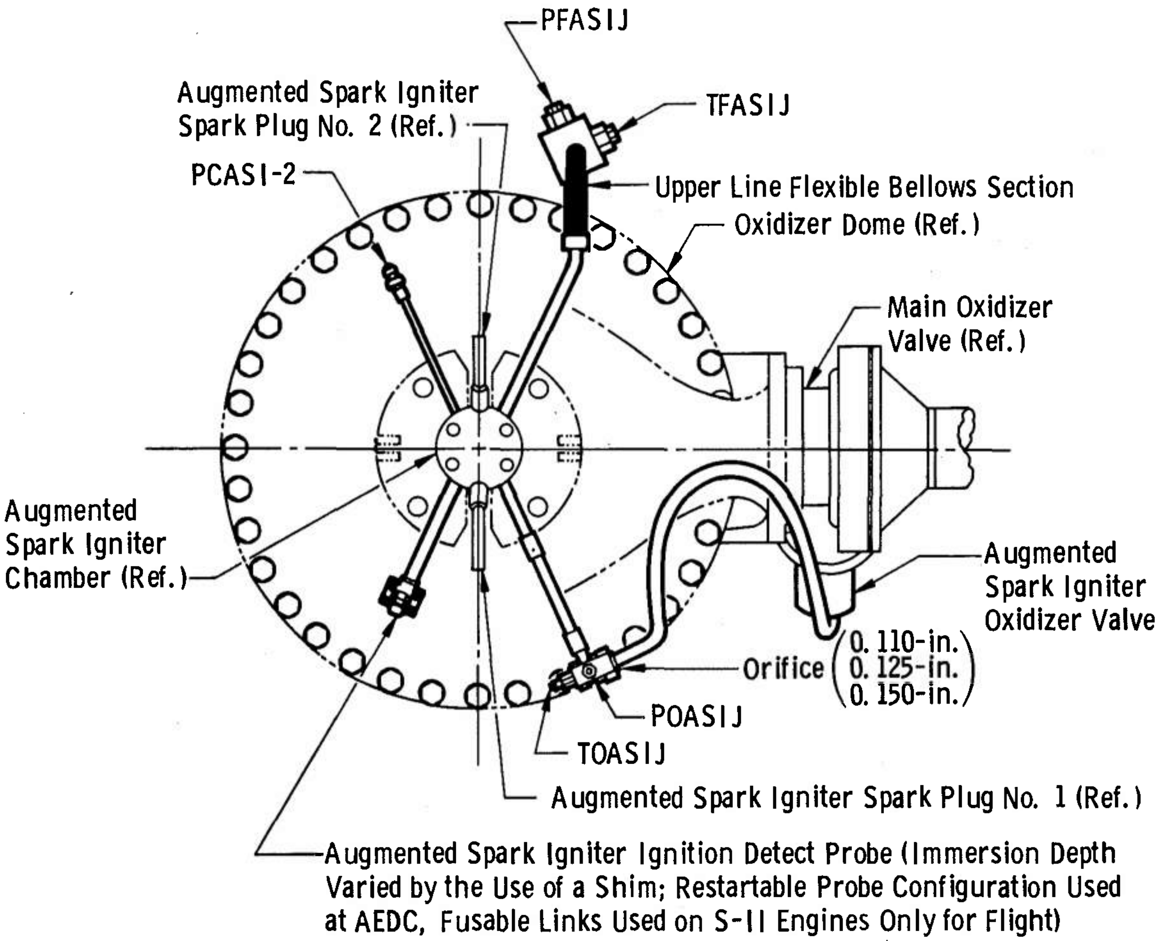


Fig. IV-1 Augmented Spark Igniter Propellant Supply Configuration, Engine J-2052

APPENDIX V
AUGMENTED SPARK IGNITER DATA REDUCTION

STRAIN

Strain-gage data were recorded on the FM system only. These data for tests 40 and 41 were transcribed to oscillograph to obtain time-history records for each firing. The oscillograph speed was 8 in./sec using a tape speed on 60 in./sec for both recording and transcribing. Galvanometers were selected to provide a maximum frequency response capability of 3000 Hz. Manual data reduction techniques were applied to the oscillogram records to obtain vibration and strain amplitude levels. Selected time intervals of steady-state strain and vibration data were analyzed for frequency spectrum using a Honeywell Model 9300 frequency wave analyzer. Tape loops were made from the magnetic tape data records which were analyzed for power spectral density of each parameter using 1-sec averaging time and 1-Hz bandwidth over the frequency spectrum of 2 to 300 Hz and 10-Hz bandwidth over the spectrum from 300 to 1000 Hz.

TEMPERATURE

Augmented spark igniter temperature data during the start transient were derived from the restartable ignition detect probe output voltage (not a flight item). The ignition detect probe is not a data sensor, but an electrical control device, and is incapable of measuring absolute temperature. Furthermore, the probe placement and immersion depth are such that the probe is cooled by the swirl injection pattern of the fuel entering the augmented spark igniter chamber. The ignition detect probe is a platinum element device that registers "ignition detected" when 10-ohm differential resistance exists between the sensing element and the reference element on first rise in probe temperature as ignition occurs in the augmented spark igniter. Once ignition has been detected, the probe has accomplished its basic function. As the probe temperature continues to rise, the reference element also changes resistance along with the sensing element. Recognizing these probe characteristics, since there are no provisions for measuring actual augmented spark igniter temperature, the ignition detect probe output amplifier voltage (VIDA) is used in this report as a gross indicator of chamber temperature during the ignition phase of the engine start transient. Relative differences in probe output voltage test-to-test are the best available indicator of augmented spark igniter chamber temperature transients. Temperature peak levels are derived using the platinum resistance

curve and the amplifier characteristic curve (periodically checked between tests using a discrete-resistance substitution technique) shown in Fig. V-1 without any attempt at error correction in this report. Temperature levels are quoted only to the nearest 100°F. Amplifier voltage output time-histories are presented during the ignition phase of each of the firings reported herein.

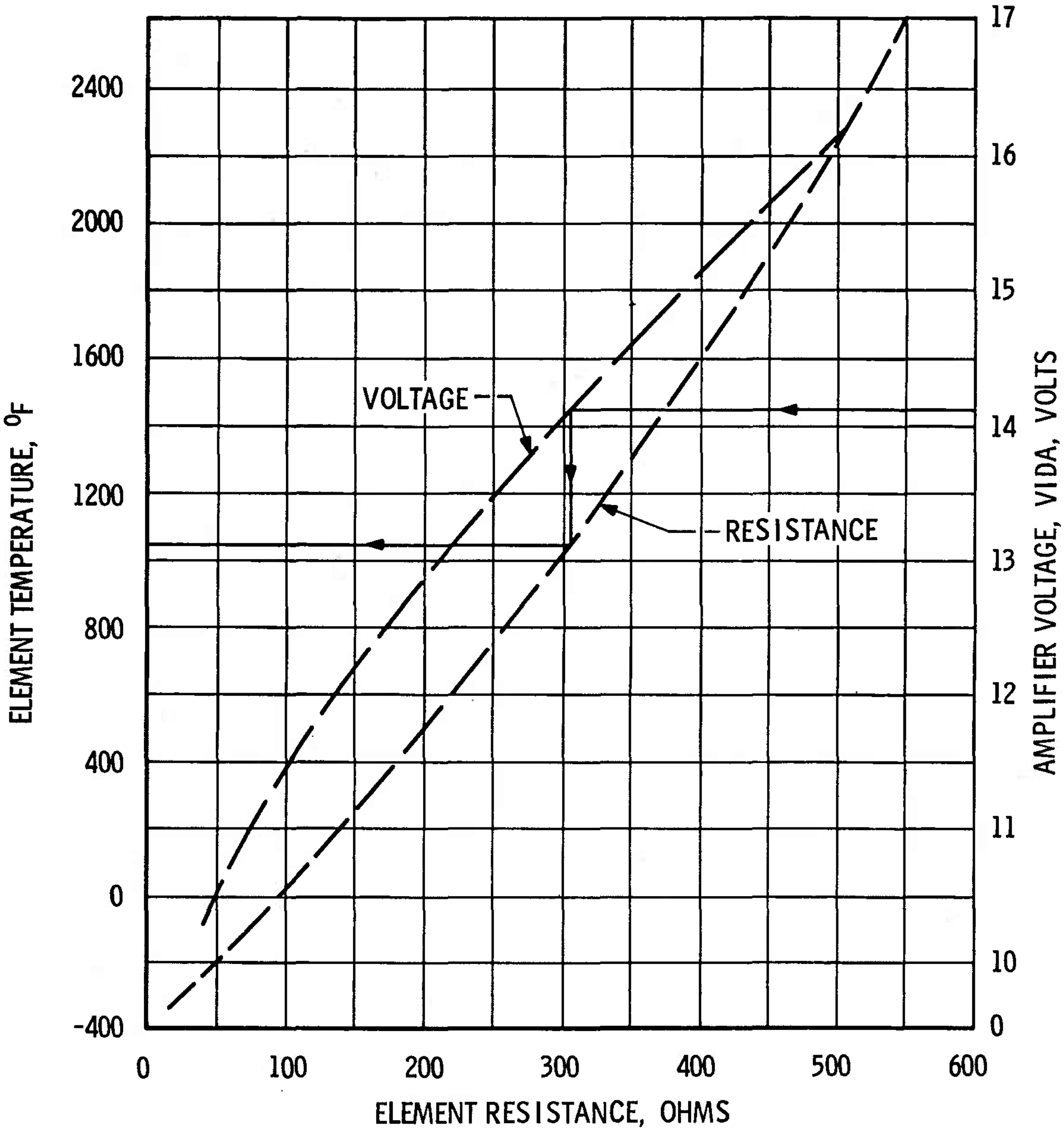


Fig. V-1 Augmented Spark Igniter Ignition Detect Probe Temperature Data Reduction

APPENDIX VI
DEFINITIONS OF TERMS

THRUST CHAMBER IGNITION

Thrust chamber ignition, mentioned in the article 4.2 firing discussions and given in Table VI, Appendix II, is the time of first rise to 100-psia chamber pressure during an engine start transient. This is an arbitrary definitive term which is useful for test-to-test comparison purposes and which marks the beginning of sufficient pressure increase from propellant combustion in the thrust chamber to force a rise in oxidizer dome pressure that eventually triggers the "main-stage" pressure switches in the oxidizer dome. Actually, thrust chamber ignition begins nearly 0.5 sec earlier as the main oxidizer valve is travelling to the first-stage position. The reduced first-step position of 14 deg is incorporated for the main oxidizer valve to provide a reduced flow rate (roughly oxidizer-to-fuel mixture ratio of 1 in the thrust chamber) until all of the oxidizer posts of the injector develop sustained liquid flow. Low grade burning takes place far down in the combustion chamber from the time that the first combustible mixture of gaseous oxidizer and fuel contacts the augmented spark igniter "torch" (Ref. 8) until liquid oxidizer flow is established at the injector, chamber pressure begins to rise, and the combustion flame-front progresses back up the chamber toward the injector. The first ignition of propellants (sometimes referred to as main propellant ignition) is detectable on the engine accelerometers during all J-2 engine starts under the pressure altitude conditions of J-4 cell. [The colder the thrust chamber at the time of start tank discharge, indicated by how long fuel injection temperature has indicated -400°F or colder during the ignition phase of the start sequence, the harder the register of main propellant ignition on the accelerometers and, generally, the longer the ignition delay time from main-stage control solenoid (which marks initiation of the main-stage phase of the start sequence).] For very cold thrust chamber starts, there is an abrupt increase in thrust chamber pressure in the order of 35 psia at main propellant ignition.

OXIDIZER DOME PRIME

Oxidizer dome prime is the term used to describe the first filling of the oxidizer dome (from the main oxidizer valve gate to the floor of the oxidizer injector) with single-phase liquid oxidizer. Chilldown of the oxidizer dome begins immediately with the initial opening of the main oxidizer valve and progresses as oxidizer, passing through the

injector, undergoes the transition from gaseous to two-phase to single-phase liquid flow. As liquid-phase flow through the injector begins to be established, localized regions of higher mixture ratio in the combustion chamber cause an abrupt rise in thrust chamber pressure, usually from about 50 to about 150 psia, documented as thrust chamber ignition time. Coincident with this abrupt rise in thrust chamber pressure are approximately 300-Hz frequency, high amplitude rises[1] in oxidizer dome pressure that dampen out once fully developed liquid flow is established through the oxidizer injector posts and uniform mixture ratio exists across the combustion chamber. When the oxidizer dome priming action is severe, there are, coincident with the oxidizer dome pressure peaks, high frequency thrust chamber pressure oscillations associated with acoustic resonance modes of the combustion chamber, i. e., combustion instabilities, which are triggered by the abrupt changes in the combustion process caused by the priming action. It is these instabilities that the vibration safety cutoff circuitry detects and registers as vibration safety counts.

The terms "oxidizer dome prime" and "thrust chamber ignition", therefore, are closely related, marking both the initiation of the oxidizer dome pressure rises and the increase in combustion chamber pressure from low grade burning to above the arbitrary 100-psia level.

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[1]As this report was being written, data were obtained on subsequent (to test 41) tests using a high frequency response Photocon® pressure transducer flush mounted to the oxidizer dome showing the above-described pressure oscillations which are not detectable with the low frequency response measurements in use on engine S/N J-2047. These high response data will be published in later reports.

APPENDIX VII
METHOD OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE VII-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower
C	Coefficient
C*	Characteristic velocity, ft/sec
D	Diameter, in.
F	Thrust, lb_f
H	Head, ft
h	Enthalpy, Btu/lb_m
$\dot{I}$	Impulse
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio, O/F
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Differential pressure, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiencies
θ	Degrees, angular position
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FM	Fuel measured
FV	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
TO	Turbine oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

THRUST

Thrust Chamber, Vacuum

$$F_{CV} = C\,(P_C)^2 + B\,(P_C) + A$$

Empirical Determination from Curve Fit of Thrust versus P_C

Thrust Chamber

$$F_C = F_{CV} - P_{AA}\,A_e$$

$$A_e = A_{em} + 12.8$$

$$P_{AA} = \text{Measured Cell Pressure}$$

Engine, Vacuum

$$F_{EV} = F_{CV}$$

Engine

$$F_E = F_C$$

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = \text{Standard } 0.9 \text{ lb/sec}$$

$$W_{XF} = \text{Standard } 2.1 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\,A_{TIF}\,K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

Normalized engine and thrust chamber vacuum data calculated as measured, except all flows are normalized using standard inlet pressures, temperatures, and densities listed below:

$$P_{IO}\ STD = 39\ psia$$

$$P_{IF}\ STD = 30\ psia$$

$$\rho_{IO}\ STD = 70.79\ lb/ft^3$$

$$\rho_{IF}\ STD = 4.40\ lb/ft^3$$

$$T_{IO}\ STD = -295.2°F$$

$$T_{IF}\ STD = 422.5°F$$

SPECIFIC IMPULSE

Engine

$$I_{SE} = \frac{F_E}{\dot{W}_E}$$

$$\dot{W}_E = \dot{W}_{EO} + \dot{W}_{EF}$$

Engine, Vacuum

$$I_{SEV} = \frac{F_{EV}}{\dot{W}_{EV}}$$

$\dot{W}_{EV} = \dot{W}_E$ Normalized using standard inlet pressures, temperatures, and densities

Chamber

$$I_{SC} = \frac{F_C}{\dot{W}_C}$$

$$\dot{W}_C = \dot{W}_{CO} + \dot{W}_{CF}$$

Chamber, Vacuum

$$I_{SCV} = \frac{F_{CV}}{\dot{W}_{CV}}$$

$\dot{W}_{CV} = \dot{W}_C$ Normalized using standard inlet pressures, temperatures, and densities

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\ P_C\ A_t}{\dot{W}_C}$$

$$K_7 = 32.174$$

Thrust Chamber, Vacuum

$$C^*_V = \frac{K_7\ P_{CV}\ A_t}{\dot{W}_{CV}}$$

$$K_7 = 32.174$$

Nozzle

$$C^*_N = \frac{C^*}{K_6}$$

$$K_6 = 1.086$$

Nozzle, Vacuum

$$C^*_{NV} = \frac{C^*_V}{K_6}$$

$$K_6 = 1.086$$

THRUST COEFFICIENT

Engine

$$C_F = \frac{F_C}{P_C A_t}$$

Engine, Vacuum

$$C_{FV} = \frac{F_{CV}}{P_C A_t}$$

DEVELOPED PUMP HEAD

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

ρ = National Bureau of Standards Values f(P,T)

Fuel

$$H_F = 778.16\, \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

Fuel and Oxidizer Vacuum

Conditions normalized using standard inlet pressures, temperatures, and densities.

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_F = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC} Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$Y_O = 1.000$$

$$K_{40} = -5.053 \qquad K_{50} = 3.861 \qquad K_{60} = 0.0733$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} \; H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \; \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B\,(P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

if $P_{OO} \geq 1010$

set $P_{OO} = 1010$

$$\ell n\, R_v = A + B\,(\theta_{PUVO}) + C(\theta_{PUVO})^3 + D\,(e)^{\frac{\theta_{PUVO}}{7}} + E\,\theta_{PUVO}\,(e)^{\frac{\theta_{PUVO}}{7}} + F\left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$A = 5.566 \times 10^{-1}$

$B = 1.500 \times 10^{-2}$

$C = 7.941 \times 10^{-6}$

$D = 1.234$

$E = -7.255 \times 10^{-2}$

$F = 5.069 \times 10^{-2}$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10}\ \Delta h_F\ W_T$$

$$\Delta h_F = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF}\ H_F}{\eta_F}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.415$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO}$$

$$B_{PO} = K_5 \left(\frac{W_{PO}\ H_O}{\eta_O}\right)$$

$$K_5 = 0.001818$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \left(\frac{W_{PF}\ H_F}{\eta_F}\right)$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7\ \gamma_{H2}}{\gamma_{H2} - 1}\ (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2} - 1}{\gamma_{H2}}}\right]^{1/2} \frac{A_{NB}\ P_{BNI}}{(R_{H2}\ T_{BIR})^{1/2}}$$

$$P_{RNC} = f\ (\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = D_{NB}/D_B$$

$$\gamma_{H2},\ M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13}\ (D_{NB})^2$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS}\left[1 + K_8\left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4{}_{TEF}\,M_{H2}}\left(\frac{\gamma_{H2}-1}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$K_8 = 38.90$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1\,(T_{H1})^3 + C_1\,(T_{H1})^2 + B_1\,(T_{H1}) + A_1$$

$A_1 = 0.2575$

$B_1 = 5.586 \times 10^{-4}$

$C_1 = -5.332 \times 10^{-9}$

$D_1 = 1.1312 \times 10^{-11}$

$T_{H1} = T_{TIFM}$

Flows

$$TC^*{}_{TIF} = D_2\,(T_{H1})^3 + C_2\,(T_{H1})^2 + B_2\,(T_{H1}) + A_2$$

$A_2 = 4.4226 \times 10^3$

$B_2 = 3.2267$

$C_2 = -1.3790 \times 10^{-3}$

$D_2 = 2.6212 \times 10^{-7}$

$$P_{TIF} = P_{TIFS}\left[1 + K_8\left(\frac{W_T}{P_{TIFS}}\right)^2 \frac{T_{H1R}}{D^4{}_{TIF}\,M_{H1}}\;\frac{\gamma_{H1}-1}{\gamma_{H1}}\right]^{\frac{\gamma_{H1}}{\gamma_{H1}-1}}$$

$K_8 = 38.8983$

Note: P_{TIF} is determined by iteration.

$T_{H1R} = T_{TIFM} + 460$

$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{H1R}, r_G)$

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13. ABSTRACT

Fourteen firings of the Rocketdyne J-2 rocket engine performed in Test Cell J-4 of the Large Rocket Facility, using modified augmented spark igniter propellant supply lines, are reported herein. These firings were accomplished during test periods J4-1801-39 through J4-1801-41 at pressure altitudes ranging from 88,000 to 109,000 ft at engine start. These were the initial firings at simulated altitude conditions, all related to Saturn V/S-IVB conditions, incorporating engine modifications that were performed as a result of malfunctions that occurred during the flight of vehicle AS-502 on April 4, 1968. Engine start transient evaluations, augmented spark igniter propellant line strain data, engine steady-state and transitory vibration data, and calculated engine steady-state performance data are included. Satisfactory engine operation and augmented spark igniter operation were obtained. The accumulated firing duration was 181.7 sec.

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strain						
vibration						
combustion stability						

1. Rocket motors -- J-2

2 " " -- Performance

3 " " -- Ignition

4 " " -- Combustion

5 " " -- Vibration

6 Combustion -- Stability

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